AD-A039 223 PRINCETON UNIV N J FLIGHT RESEARCH LAB F/G 1/2

A STUDY OF LIGHTPLANE STALL AVOIDANCE AND SUPPRESSION.(U)

FEB 77 D R ELLIS, J STEINBERGER DOT-FA74WA-3480

UNCLASSIFIED FAA-RD-77-25 NL

1 OF 2

AD A039223

Report No. FAA-RD-77-25

(12)

B.S.

AD A 039223

A STUDY OF LIGHTPLANE STALL AVOIDANCE AND SUPPRESSION

David R. Ellis

Flight Research Laboratory
Aerospace and Mechanical Sciences Department
Princeton University
Princeton, N.J. 08540

Final Report

February 1977

Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

19

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. 18 FAA-RD-77-25	2. Government Accession No.
3. Recipient's Catalog No.	
4. Title and Subtitle 6 A STUDY OF LIGHTPLANE STALL AVOIDANCE AND SUPPRESSION.	5. Report Date 11 Feb~~ruary~~ 1977
	6. Performing Organization Code 12 108p.
7. Author(s) 10 David R. Ellis, J. Steinberger	8. Performing Organization Report No.
9. Performing Organization Name and Address Flight Research Laboratory, Aerospace and Mechanical Sciences Department Princeton University Princeton, New Jersey 08540	10. Work Unit No.
	11. Contract or Grant No. 15 DOT-FA74WA-3480 Nov
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590	13. Type of Report and Period Covered 9 Final Report
	14. Sponsoring Agency Code ARD-530

15. Supplementary Notes. FAA Technical Monitor: E. Boothe
•Accident analysis subcontracted to Aircraft Safety Consultants, Inc. Palo Alto, Ca.
•Bibliography compiled by J. Steinberger, Princeton University

16. Abstract

Although the stall/spin accident record has improved significantly since the 1945-1948 period, the stall-related accident still accounts for a large percentage of general aviation fatalities. This study represents an effort to obtain a better understanding of the circumstances, causes, and factors which result in unintentional stalls at low altitude. A three-part program was conducted, involving extensive computer analysis of stall-related accidents for the period 1965-1973, flight evaluation of the low speed handling qualities and stall behavior of seven lightplanes, and generalized experiments to study pilot/airplane interactions in the high angle of attack regime using an in-flight simulator. The results indicate that further work is especially warranted in the areas of pilot education and training, stall warning systems, and application of new aerodynamic technology. In addition, renewed consideration should be given to the idea of limiting control power in non-acrobatic airplanes.

407 310

17. Key Words (Selected by Author(s))	18. Distribution Statement
Stall Stall Warning Handling Qualities In-Flight Simulation	Document available to the public through the National Technical Information Service, Springfield, Va. 22151.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	108	

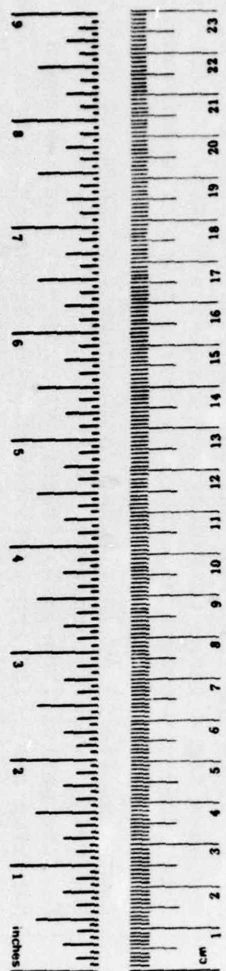
*For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

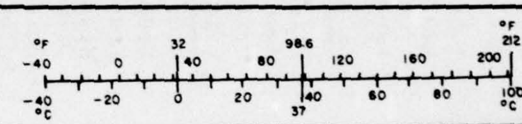


TABLE OF CONTENTS

LIST OF ABBREVIATIONS AND SYMBOLS

ALL	Fatal plus non-fatal accidents
AR	Accident rate
CG	Center of gravity
$C_{L_{max}}$	Maximum lift coefficient
δ_f	Flap deflection, degrees
D	Drag, lb
D_α	Drag due to angle of attack derivative, $1/m\ (\partial D/\partial\alpha)$ ft/sec^2/rad
D_V	Drag due to airspeed derivative, $1/m\ (\partial D/\partial V)$, 1/sec
FATAL	Fatal accidents only
FAR	Federal Aviation Regulations
F_s	Longitudinal control force, lb (commonly called "stick force")
F_s/n	Maneuvering force gradient, lb per g
g	Gravitational acceleration, ft/sec^2
I_y	Moment of inertia about pitch axis, slug-ft^2
kt	Knots
L_α	Lift due to angle of attack derivative, $1/m\ (\partial L/\partial\alpha)$, ft/sec^2/rad
L_V	Lift due to airspeed derivative, $1/m\ (\partial L/\partial V)$, 1/sec
m	Mass, slugs
mph	Miles per hour
M	Pitching moment, ft-lb
M_α	Pitching moment due to angle of attack derivative, $1/I_y\ (\partial M/\partial\alpha)$, rad/sec^2/rad
$M_{\dot\alpha}$	Pitching moment due to angle of attack rate derivative, $1/I_y(\partial M/\partial\dot\alpha)$, 1/sec
$M_{\dot\theta}$	Pitching moment due to pitch rate derivative, $1/I_y\ (\partial M/\partial\dot\theta)$, 1/sec
M_V	Pitching moment due to airspeed derivative, $1/I_y\ (\partial M/\partial V)$, rad/sec^2 per ft/sec
n	Load factor, g units
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NTSB	National Transportation Safety Board
R/C	Rate of climb, ft/min.
R/S	Rate of descent, ft/min.

T	Thrust, lb
TOTAL	Total of all accident types
T_v	Thrust due to airspeed derivative, $1/m\ (\partial T/\partial V)$, 1/sec
V_i	Indicated airspeed, mph or kt
V_s	Stall airspeed, mph or kt
V_{trim} or V_o	Trim airspeed, mph or kt
α	Angle of attack, degrees or radians
$\dot{\alpha}$	Angle of attack rate, deg/sec or rad/sec
$\dot{\theta}$	Pitch rate, deg/sec or rad/sec

SECTION I

INTRODUCTION

A. BACKGROUND

Although the 1903 flight at Kitty Hawk was a magnificent accomplishment, the Wright Brothers were far from being competent pilots at that point. It was not until September of 1904 that the first full circle was performed, and well into the 1905 flying sessions they were still encountering frequent out-of-control situations (References 1 and 2). In one recorded case, Wilbur inadvertantly shut off the engine and in the ensuing confusion allowed the machine to nose up and stall; the impact caused considerable damage but no injury. In time, the need for a nose-down control input to unstall the wing was recognized, and diving for recovery from what we now term high angle of attack situations became part of their flying technique.

Despite the passing of over seventy years of powered flight, during which the phenomenon of stalling has been studied rather extensively (as a quick scan of the Bibliography will confirm), aviation has experienced a continuing stall-related accident problem. Periodically, major efforts have been directed toward the development of "safe airplanes." In the late 1930's, NACA activities in this area led to several production lightplanes with considerably improved low speed flight characteristics compared to previous designs. The level of research and development activity at any given time seems to depend on how clearly everyone perceives that the accident record is not acceptable and that simple remedies, especially those which depend upon enhanced pilot awareness and capability, won't entirely suffice. This is evident in the recent surge of military R&D in the stall/spin area (Reference 3).

In the general aviation case, renewed research activity has come largely as a result of NTSB Report AAS-72-8, "Special Study - General Aviation Stall/Spin Accidents 1967-1969" (Reference 4). The report pointed out that although the stall/spin accident record had shown a marked improvement over the immediate post-war years (for 1945 through 1948, stall/spin accidents accounted for 48% of all fatal accidents; for the period 1967 through 1969 this dropped to 22%), the stall-related accident still accounted for a large portion of the fatalities and injuries in general aviation. Considering the projected size and growth rate of general aviation, an improvement in the record would clearly be required to prevent an accompanying increase in injuries and fatalities.

Among the recommendations of the NTSB report were several which urged the FAA, together with NASA, to conduct studies and evaluations which would point to areas of design, equipment, and operation which might bring about an improvement in the stall/spin accident record. At the time (1972) NASA was already deeply involved in light airplane spin research (Reference 5). The study reported here represents an FAA response to the NTSB recommendation in the area of stall and mush accidents.

B. THE PRESENT STUDY

The existence of a continuing history of stall/spin accidents tends to be somewhat perplexing to anyone deeply involved in airplane design and

certification, or pilot training and licensing, because seemingly reasonable efforts have been made to prevent such occurrences. Specifically, the following might be noted:

- Stall and spin characteristics which are accepted as "normal" can usually be achieved in an airplane through well-known design approaches and aerodynamic features (although a good deal of "cut-and-try" testing may be required).
- The Federal Air Regulations require all certificated lightplanes to exhibit clear and distinctive stall warning, and to respond to normal use of the controls in such a way that neither excessive altitude nor dangerous attitudes are encountered during stalls and recoveries; spin recovery must always be possible with normal technique.
- Student pilots are instructed intensively in stall recognition and recovery (though spin training is not required) and must successfully demonstrate this knowledge before being issued a private license.

If stalls are not inherently dangerous, and if all pilots know how to recognize and recover from them, then one must seriously question why so many stall-related accidents continue to occur. The evidence suggests that although the items listed above might adequately cover intentional stalls and spins, they do not adequately cope with the case of an unintentional stall— one encountered while the pilot is intent on accomplishing some other maneuver, particularly at low altitude.

Unintentional Stalls. In focusing attention on this matter of unintentional stalls, the interactions between the following factors would seem to be important:

- Performance characteristics at low speeds
- Handling qualities at low speeds
- Pilot behavior in low speed flight situations

The performance characteristics which are significant here are those related to the takeoff and landing environment and to accelerated flight conditions (steep turns, pull-ups), where the pilot may be so intent upon achieving a desired flight path that precise control is not exercised. For example, if climb performance is particularly sensitive to being at the proper speed, or sensitive to flap deflection, then it is possible to imagine how lack of attention to those factors could contribute to the pilot's stalling the airplane in the process of trying to clear an obstacle.

The handling qualities factors are those which influence the ability to fly the airplane precisely and safely at low speeds. The near-stall and post-stall behavior of the airplane are most important, of course; lateral controllability, pitching behavior, change of characteristics with power and flaps, and effects of sideslip come to mind as significant factors. However, in seeking factors which will lead a pilot from a normal flight condition into an unintentional stall, the "feel" characteristics — the stick force and position gradients — would appear to warrant special attention, since they help determine how well speed and angle of attack can be controlled.

Finally, and perhaps most important, it is necessary to consider the pilot's likely behavior in order to understand and evaluate airplane characteristics with respect to inadvertant stalls. In a stressful situation, can he recognize the onset of a stall and apply quick recovery action?

The record indicates that too often he can't, but the reasons for this are not clearly evident. However, some possible influencing factors may be listed: poor state of knowledge stemming from inadequate basic training or lack of familiarity with the type of airplane or type of flying; or insufficient current experience, especially in stalls, slow-flight maneuvering, and maximum performance operations. Even given adequate knowledge and practice, a pilot may still have the problem of "ground shyness," the tendency to be intimidated by the proximity of the ground to the point of not using the recovery techniques which he has mastered at high altitude.

The Research Program. The research reported here represents an effort to illuminate, at least in a preliminary way, the ways in which the various factors mentioned above relate to the accident record of recent years: Three main elements were involved in the study:

- TASK 1 -

  An analysis of stall-related accidents.

- TASK 2 -

  Flight evaluations of production airplanes.

- TASK 3 -

  In-flight simulation experiments.

TASK 1 - Accident Analysis. This first element of the program consists of an extensive analysis of stall-related accidents for the period 1965-1973, using data from NTSB coded magnetic tapes. The aim was to obtain an overview of the circumstances and conditions surrounding this type of accident, and to identify those airplanes with distinctly low and high frequency of involvement.

The bulk of this task was performed under subcontract by Aircraft Safety Consultants, Inc., of Palo Alto, California. Section II of the report contains a summary of the results; a detailed version is given in Appendix A, with supporting material in Appendices B and C.

TASK 2 - Flight Evaluations. The following airplanes were selected for evaluation in the program:

- Bellanca Citabria 150
- Cessna 182 Skylane
- Cessna 150
- Cessna 177 Cardinal
- Grumman American Yankee AA-1
- Grumman American Trainer AA-1B
- Piper Cherokee 140

Task 1 findings weighed heavily in the selection of the various airplanes, and the list contains examples with both very good and very poor stall accident records. It was felt important to include commonly used trainers (the Cessna 150 and Cherokee 140 in particular) regardless of their records. Local availability became a final factor. The Grumman American Trainer was not originally on the list, since it was a 1974 model and did not figure in the records used for the Task 1 accident analysis. It was included in order to assess possible improvements in stall behavior over the AA-1 attributable to its modified wing leading edge.

The evaluations themselves were largely qualitative assessments of low speed handling and stall characteristics, with simple measurements being made where possible. The aim of the experiments, it must be emphasized, was not to gather data for the purpose of checking compliance with regulations, but rather to provide orientation and background in this area of unintentional stalls. Section III of the report deals with general observations of the low speed handling of the seven Task 2 airplanes, while more detailed comments are contained in Appendix D. Other results of a topical nature, such as control force characteristics and stall warning are covered in separate sections of the report.

Task 3 - In-Flight Simulation Experiments. The third element of the study made use of the Navion in-flight simulator described in Appendix F. Special features were incorporated in the control system to permit simulation of the essential features of the stall break (a lift loss and nose-down pitching moment) while retaining a reasonable stall margin in the basic vehicle. Various stall warning devices, including horn, stick shaker, and angle of attack indicators could be selected. The basic Navion aerodynamic characteristics are reasonably typical of this class of airplane, and were retained for the "baseline" configuration about which variations were made. Values of the longitudinal stability derivatives for a 70-kt reference condition are listed at the end of Appendix F.

Here the major objective was to explore in a generalized way the interactions between performance and handling characteristics and the piloting task. (It is important to note that typical lightplane characteristics were simulated, but particular airplanes were not.) The usual format of the experiments called for circuits of the airfield with a 75 kt approach and a touch-and-go landing followed by a 70 kt (maximum angle) climb and turn. On the downwind leg the evaluation pilot was asked to perform a low-altitude 360° or 720° circle about an object on the ground using outside references. At various points in the pattern he would perform intentional stall and control abuses. Appropriate measurements, such as control activity, airplane motions, and flight path time histories were recorded by means of telemetry. Formal evaluations were carried out by one Princeton and one FAA pilot; various other FAA and industry pilots were exposed to the stall simulation and stall warning devices.

Testing in this phase was somewhat limited in scope and extent, but did serve to demonstrate the effectiveness of in-flight simulation for studies of pilot/airframe behavior in the high angle of attack flight regime. The results are discussed in Sections IV, V, and VI of the report.

SECTION II

THE STALL/MUSH ACCIDENT RECORD - A SUMMARY

In this section the material contained in Appendix A - AN ANALYSIS OF SINGLE-ENGINE LIGHTPLANE STALL ACCIDENTS (1965-1973) is summarized to provide background and orientation for the later sections of the report. The analysis is based mainly upon a review of domestic accidents involving 31 different (by make and model) lightplanes selected according to the following criteria:

- Single-engine fixed wing design
- Used primarily for purposes other than crop control
- At least 500 active in the U. S. in 1973

Of the 30,606 total accidents reviewed for the group of 31 aircraft (listed separately in Appendix B and referred to collectively as Group 32 in the analysis) 3,467 were due to stall, spin, spiral, or mush. As noted in Section I, the primary emphasis is placed on the stall and mush cases. The data were obtained from two sources:

- NTSB accident records, primarily from coded magnetic tapes
- FAA estimates of hours flown for each make and model

A. ACCIDENT DISTRIBUTIONS

Accident Rates. For the nine years of the study, there were 3,467 stall-related accidents for the group of 31 airplanes (no crop control usage included) of which 1,029 were fatal. This amounted to 29% of the total fatal accidents of all types, and 11% of all accidents. Fatal stall accidents occurred at a rate of about 0.35 per 100,000 flight hours; the combined stall, spin, spiral, and mush fatal accident rate was about 0.7 per 100,000 hours.

Type of Operator. The operator in most of the cases (over 50%) is a private owner; this is followed by fixed-base operator (a little over 20%), flying club (slightly less than 10%), corporate/executive and flying school (a little less than 5% each).

Kind of Flying. Pleasure flying accounts for 63% of all stall and mush accidents and 68% of the fatal stall occurrences. This may be compared with the distribution for total accidents of all kinds, where pleasure flying is involved in 55% of the cases.

Instructional flying is being done in 18% of the stall and 14% of the mush accidents; by comparison, 21% of all accidents of all types involve instruction.

Phase of Flight. The most common flight phase for stall accidents is the so-called "in-flight" phase, which encompasses essentially everything except takeoff and landing. Of the fatal stall cases, 63% occur in this in-flight phase, 15% in takeoff, and 21% in landing. Most of the fatal in-flight accidents are associated with acrobatics, buzzing, and low passes, and relatively few occur in climb to cruise, normal cruise, and descent operations. The pre-stall maneuver is not known in many cases, but an analysis of 48 fatal stall accidents occurring in 1973 indicated that 60% involved turning and 85% involved turning and/or climbing.

A mush type accident is most likely to occur during takeoff.

Conditions of Weather and Light. Stall and mush accidents are essentially good weather phenomena, with 96% of the stall and 99% of the mush cases happening in VFR weather; more than 90% of all such accidents occur during daylight hours.

Pilot Experience. Accidents of all types, including stall and mush accidents, tend to happen most frequently to pilots with low total time, low time in type, and to young pilots. Unfortunately, the distribution of experience for all flying done on the airplanes of Group 32 is not available, so the factor of exposure level (that is, who does the most flying) cannot be evaluated directly. However, it is possible to compare stall and mush accidents with a more random type, the "true" engine failure accident (where the engine failure was not due to a pilot error, such as fuel mismanagement), with the following result: pilots with less than 500 hours total flying time or 100 hours in type are more likely to have a stall or mush accident than a true engine failure accident; with more experience in either category the engine failure accident is more likely.

There is insufficient information available at this point to evaluate other important factors such as how much the pilot's experience was recent, and how much dual instruction he had received in the particular type of airplane involved in the accident.

Stall Warning Indicator. One-third of the stall accidents and one-half of the spin accidents of the group for which data are available involved airplanes which did not have stall warning indicators. One interpretation of this result is that some of the accidents might have been avoided if such a device had been installed; another suggests that since accidents continue to happen with standard stall warning systems installed, serious consideration should be given to their improvement.

B. CAUSES AND FACTORS

The NTSB has the responsibility for determining the "probable cause" of each accident, and has established some 860 codes for the purpose. The same codes may be cited as "factors"; the two terms are formally defined as follows:

CAUSE: Had the condition or event been prevented, the accident would not have occured.

FACTOR: A related condition or event, the omission of which would not necessarily have prevented the accident.

The most common cause cited for stall accidents is, "Pilot in command failed to obtain or maintain flying speed." It must be assumed that the statement means that the stall angle of attack was reached or exceeded, and the flight path was adversely affected. At any rate, the citation clearly implies that the pilot is at fault, and is listed in 91% of stall accidents and 76% of mush accidents. When the pilot is not cited for failure to "obtain or maintain flying speed," some other pilot error is almost always found in stall accidents. This is discussed further in Appendix A.

C. RESULTS FOR INDIVIDUAL AIRCRAFT

In this section accident patterns for individual makes and models are compared with the patterns for the 31 airplanes taken as a group (Group 32, Appendix C). A Chi-square statistical test is applied to determine whether

the observed differences and the sample size are sufficiently large to make the finding significant.

Accident statistics for the 31 individual airplanes and for Group 32 are shown in Table II-1. Crop control flight hours and accidents are excluded; the accident rates shown are per 100,000 flight hours. The term TOTAL is used to indicate that accidents from all causes are being considered; ALL refers to the sum of fatal and non-fatal accidents.

TABLE II-1. TOTAL ACCIDENT STATISTICS FOR 31 SINGLE-ENGINE AIRCRAFT (1965 - 1973)

GR.	SHORT	TOTAL ACCIDENTS		HOURS	TOTAL ACCID. RATE		RELATIVE TO GR.#32; CHI-SQUARE			
#	NAME	FATAL	ALL	X 10^5	FATAL	ALL	FATAL		ALL	
1	AERON.11	18	162	3.595	5.01	45.06	+98%	H	+112%	VH
2	ERCOUPE	49	505	13.727	3.57	36.79	+41%	H	+73%	VH
3	YANKEE	35	194	6.060	5.78	32.02	+128%	VH	+50%	VH
4	B-23	63	789	25.505	2.47	30.94	-2%		+45%	VH
5	BONANZA	342	1840	105.359	3.25	17.46	+28%	VH	-18%	VL
6	BELLANCA	27	216	6.517	4.14	33.14	+64%	H	+56%	VH
7	CITABRIA	162	1293	35.386	4.58	36.54	+81%	VH	+72%	VH
8	C-140	61	991	24.944	2.45	39.73	-3%		+87%	VH
9	C-150	387	4290	284.885	1.36	15.06	-46%	VL	-29%	VL
10	C-170	64	712	21.541	2.97	33.05	+17%		+55%	VH
11	C-172	343	2723	192.896	1.78	14.12	-30%	VL	-34%	VL
12	C-175	36	261	12.884	2.79	20.26	+10%		-5%	
13	C-180	68	853	31.933	2.13	26.71	-16%		+25%	VH
14	C-182	214	1872	104.616	2.05	17.89	-19%	L	-16%	VL
15	C-185	20	196	9.359	2.14	20.94	-15%		-2%	
16	C-206	33	319	21.948	1.50	14.53	-41%	L	-32%	VL
17	C-210	102	755	32.960	3.09	22.91	+22%	H	+8%	H
18	C-177	48	478	14.852	3.23	32.18	+28%		+51%	VH
19	MOONEY	193	1185	56.566	3.41	20.95	+35%	VH	-2%	
20	NAVION	63	304	10.094	6.24	30.12	+147%	VH	+41%	VH
21	CUB	96	635	19.051	5.04	33.33	+99%	VH	+56%	VH
22	PA-12	21	296	9.171	2.29	32.28	-9%		+52%	VH
23	PA-18	119	751	26.694	4.46	28.13	+76%	VH	+32%	VH
24	TRIPACER	160	1687	55.552	2.88	30.37	+12%		+43%	VH
25	COMANCHE	200	1398	49.117	4.07	28.46	+61%	VH	+34%	VH
26	CHEROKEE	459	3674	204.634	2.24	17.95	-11%	L	-16%	VL
27	CHER-6	65	401	23.886	2.72	16.79	+8%		-21%	VL
28	LUSCOMBE	59	731	11.088	5.32	65.93	+110%	VH	+210%	VH
29	TAYLORCR	51	339	8.404	6.07	40.34	+140%	VH	+89%	VH
30	SWIFT	33	255	3.280	10.06	77.74	+298%	VH	+265%	VH
31	STINSON	48	501	10.069	4.77	49.76	+89%	VH	+134%	VH
32	GR.#32	3639	30606	1436.573	2.53	21.30	0		0	

Percentage numbers in the two right hand columns indicate how high or low the individual airplane accident rates are compared to the group mean which appears in the bottom line. For example, the Stinson (Group 31) has a total fatal accident rate of 4.77 per 10^5 hours, which is 89% higher than the mean rate of 2.53 per 10^5 hours. The VH, VL, and L symbols are Chi-square "flags" which indicate that the rates are "very high" or "very low," or "high" or "low" compared to the group mean. The V designator indicates that the result has less then 0.1% probability of ocurring by chance; for the H or L cases the probability of a chance result is less than 5%.

There are large observed differences in the accident rates shown in Table II-1 (by a factor of 20 in some cases), and a high incidence of flags, which reflects a very large data base.

Figure II-1 presents these same results graphically. The ratio of stall and mush fatal accidents to total accidents is shown as a function of total fatal accident rate. The result for summary Group 32 is indicated by the dark circle and dashed lines; thus an airplane plotted into the lower left quadrant has both a percentage of stall/mush accidents and a total fatal accident rate lower than the group mean.

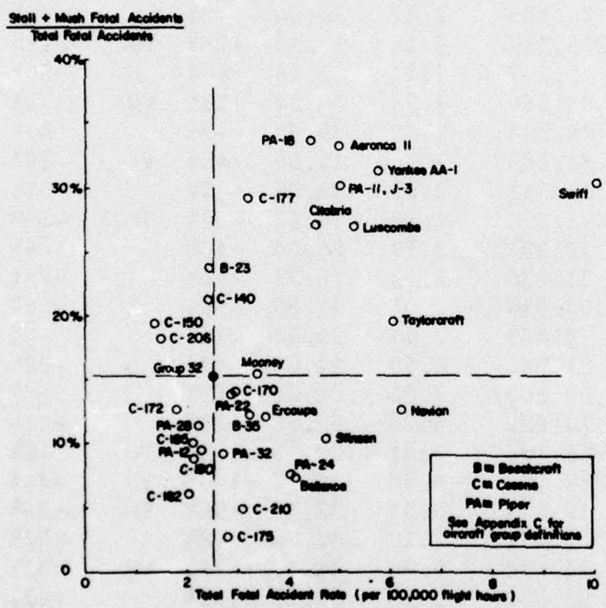


Figure II-1. Fatal Accidents for Individual Airplanes.

A final comparison is afforded by the results shown in Table II-2, which was assembled using the information from Table II-1 (which is the same as Table 15 of Appendix A) and Table 16 of Appendix A. The latter gives the stall, spin, spiral, and mush accident count for each of the airplanes and for the group as a whole. Here the various aircraft are ranked according to formulae which weight fatal accidents ten times more heavily than non-fatal ones. RANK 1 is based on accident rates, RANK 2 on percentage of total accidents represented by stall and mush. In both cases the individual rates and percentages have been compared with those for Group 32 and tested with a Chi-square technique.

The airplane with the best stall/mush safety record according to RANK 1 is the Cessna 182 and its accident rates are very low compared to the group mean. The two ranking systems show a high degree of correlation, the top three and bottom nine airplanes being the same in both (with one exception, the Taylorcraft), although in different order. Most of the airplanes near the bottom of the list are older designs; exceptions are the Cessna 177 and Grumman American Yankee, which are both relatively recent.

TABLE II-2. TWO STALL/MUSH RANKING SYSTEMS FOR 31 SINGLE-ENGINE AIRCRAFT (1965 - 1973)

RANK 1: Ranked According to (10 x FATAL Rate + ALL Rate)

RANK 2: Ranked According to (10 x FATAL % + ALL %)

			EITHER STALL OR MUSH AS FIRST OR SECOND ACCIDENT TYPES:								
	GR.	SHORT	ACCIDENT RATES:				% OF TOTAL				
RANK1	#	NAME:	FATAL		ALL		FATAL		ALL		RANK2
1	14	C-182	0.12	VL	0.60	VL	6.1%	VL	3.4%	VL	3
2	17	C-210	0.15	VL	0.43	VL	4.9%	L	1.9	VL	2
3	12	C-175	0.08	VL	1.86	VL	2.8%		9.2%		1
4	15	C-185	0.21	L	0.96	VL	10.0%		4.6%		8
5	13	C-180	0.19	L	1.47	VL	8.8%		5.5%		6
6	16	C-206	0.27		0.68		18.2%		4.7%	L	19
7	11	C-172	0.23		1.24		12.8%		8.8%		15
8	27	CHER-6	0.25		1.05		9.2%		6.2%		7
9	26	CHEROKEE	0.25		1.32		11.3%	L	7.3%	VL	11
10	9	C-150	0.26		1.50		19.4%		10.0%	H	20
11	6	BELLANCA	0.31		1.23	VL	7.4%		3.7%	L	4
12	25	COMANCHE	0.31		1.34	L	7.5%	L	4.7%	VL	5
13	5	BONANZA	0.40		1.28	H	12.3%		7.3%	L	12
14	22	PA-12	0.22		3.38		9.5%		10.5%		9
15	24	TRIPACER	0.40		1.75		13.8%		5.7%	VL	16
16	19	MOONEY	0.53		1.61	VL	15.5%		7.7%		18
17	2	ERCOUPE	0.44		3.13	VH	12.2%		8.5%		13
18	10	C-170	0.42		3.71	H	14.1%		11.2%	H	17
19	8	C-140	0.52		3.45	VH	21.3%		8.7%		22
20	4	B-23	0.59		3.25	VH	23.8%		10.5%		23
21	31	STINSON	0.50		4.67	VH	10.4%		9.4%		10
22	20	NAVION	0.79	H	2.68		12.7%		8.9%		14
23	18	C-177	0.94	VH	5.93	VH	29.2%	H	18.4%	VH	26
24	7	CITABRIA	1.24	VH	5.54	VH	27.2%	VH	15.2%	VH	25
25	29	TAYLORCR	1.19	VH	7.62	VH	19.6%		18.9%	VH	21
26	23	PA-18	1.50	VH	5.17	VH	33.6%	VH	18.4%	VH	31
27	28	LUSCOMBE	1.44	VH	6.49	VH	27.1%	H	9.8%		24
28	21	CUB	1.52	VH	8.29	VH	30.2%	VH	24.9%	VH	28
29	3	YANKEE	1.82	VH	5.94	VH	31.4%	H	18.6%	VH	29
30	1	AERON.11	1.67	VH	8.07	VH	33.3%	H	17.9%	VH	30
31	30	SWIFT	3.05	VH	15.24	VH	30.3%	H	19.6%	VH	27
	32	GR.#32	0.389		1.92		15.36%		9.02%		

SECTION III

HIGH ANGLE OF ATTACK FLIGHT CHARACTERISTICS

The discussion in this section centers on the general behavior of the airplanes tested in connection with TASK 2 of the study. The aim will not be to cover each in detail, but rather to point out common characteristics and important variations; a summary of the observed characteristics for each airplane is given in Appendix D. As noted in the introduction, the following airplanes were evaluated.

- Cessna 182 (1972)
- Cessna 150 (1972)
- Piper Cherokee 140 (1971)
- Cessna 177 "Cardinal" (1975)
- Bellanca Citabria 150 (1974)
- Grumman American Yankee AA-1 (1968)
- Grumman American Trainer AA-1B (1974)

In view of the period covered by the accident analysis, 1965-1973, it would have been desirable to sample a range of model years. Unfortunately this was not possible, and several of the airplanes may differ from the models which figured in the statistics. Perhaps the most important case is the Cessna 177, which in the version flown had more power (180 vs 150 HP) and a modified airfoil compared to early production airplanes. The Cessna 182 also had a wing leading edge with increased radius and camber compared to pre-1970 versions.

A weight and balance check was carried out for each airplane; fuel and ballast adjustments were made to achieve the weight and CG conditions listed below. Control surface travel was checked to determine compliance with specification limits (all did conform, with the exception of the Cessna 150, which had slightly more down elevator travel than called for).

Test Conditions. The test conditions concentrated on cases which would highlight differences between configurations, and combined the following:

- Power - maximum or idle
- Flap - 0° or full down
- Center of Gravity - Near aft or forward limit at takeoff gross weight
- Straight flight and 20° Banked Turns
- Coordinated (ball-centered) and rudder-free flight

It should be noted that these are not necessarily either the conditions required for compliance with FAR Part 23 or even conditions which might be routinely encountered in normal operations; the tests, it should be emphasized, were intended simply to provide orientation and background to aid in understanding the overall stall/mush problem.

A. BEHAVIOR NORMS

Acceptable behavior in high angle of attack flight is treated more in qualitative than quantitative terms in the existing regulations and recent literature (References 6, 7, and 8). The pertinent FAR Part 23

requirements (included as Appendix E) concentrate on being able to operate near and through the stall with normal, unreversed control use, with adequate control power to prevent large departures from straight flight; the emphasis is on slow approach to the stall (less than one knot per second), except for accelerated stalls which are to be demonstrated from turning flight with an approach rate of 3 to 5 kt/sec. The regulations do not require that the maximum aerodynamic lift coefficient be attainable, but only that the minimum steady speed at which the airplane is controllable be determined.

B. OBSERVED CHARACTERISTICS

The Docile Case. In the forward CG, power off, wings-level, no sideslip, zero flap case the stall could invariably be described as "docile." If a complete stall could be reached (a pitch break could not be obtained with slow deceleration in the Cessna 150, for example), the elevator could be held full up while bank angle and yaw remained controllable with modest coordinated aileron and rudder inputs. At worst, small-amplitude pitch oscillations ("nose-bobbing") and some lack of aileron effectiveness might be encountered.

Other Cases. Starting with the case above, changing any of the five variables — power, flaps, CG position, bank angle, or sideslip — generally tends to result in degraded behavior. Among the notable effects are those discussed below.

High power or aft CG movement tends to produce lowered stick force gradients, in some cases markedly so. This will be discussed in detail in the next section.

The effects of added power, flap deflection, and rearward CG all generally are in a direction which require down elevator increments to trim to the same initial speed used in the "docile" case above. The result is that more nose-up elevator (starting from trim) is available, and in most cases — especially when all three variations are combined — more control power than is needed to reach a stall is available. This is particularly striking in the case of the Cessna 150. In the "docile" configuration it barely reaches a stall with full up elevator; with combined full power, full flaps, and aft CG, the control wheel position to trim at 70 mph is nearly three inches forward of that for the "docile" airplane (which puts it only about 1/2 inch from the forward stop). Pulling the wheel back to stall finds a pitch break occurring with nearly four inches of aft travel remaining. (This phenomenon was much more pronounced with the flapped high wing airplanes tested than the low wing ones, although this may not be generally so.)

The above situation tends to produce a rather striking change in the character of the stall maneuver. Unless one takes great care in approaching the stall it is quite easy to go beyond $C_{L_{max}}$, where even small roll or yaw disturbances quickly develop into large motions, and at that point even vigorous aileron and rudder use may not prevent a departure from straight flight. Immediate recovery upon reaching the stall is the key, of course, but the behavior certainly is no longer always "docile."

In all cases tested it was possible to lower the angle of attack sufficiently to recover, but in the case cited above the cumulative trim changes left such a small increment of down elevator available for recovery that it was considered to be only barely adequate; a brisk recovery could be obtained only by reducing power or retracting flap.

The completely uncoordinated stalls might be viewed as unrealistic, but they served to underscore the importance of keeping sideslip near zero at stall entry. Particularly under high power, flap down, aft CG conditions rather violent yaw/roll departures were experienced, usually prior to any pitch break. Perhaps the most docile case observed overall was the Cessna 182, where sloppy control could be maintained ($\pm 15^o$ heading excursions, for example) even for the extreme configurations.

Stalls from turns followed the pattern of the wings-level cases, but with somewhat less predictability and more tendency toward rolling; this is undoubtedly the result of a combination of several subtle factors, including deflected aileron and rudder (to counter yaw damping and over-banking tendencies) and uncorrected build-up of sideslip just prior to the break. However, the overriding factor still appears to be whether or not there is enough control power available to exceed $C_{L_{max}}$.

Three important points should be made to conclude this section:

- The intentional stall maneuver did not appear to be inherently dangerous in any of the seven airplanes. However, many of the extreme cases demand very prompt recognition and recovery action, and use of more elevator than that required to *just reach* a stall could result in strong departure tendencies.
- The wide range of characteristics which can be encountered in what are generally considered to be "simple little airplanes" is striking. In some quarters this might be regarded as advantageous for in-depth training; in others it causes speculation that many, if not most, pilots don't receive proper training and fly unaware of the possible extremes in behavior.
- No strong systematic correspondence between the statistics of Section II and the flight test observations is apparent at this point. Perhaps the most clear-cut case is the Cessna 182; it is stallable, but considerable physical exertion is usually required, and the post-stall behavior is good. These factors apparently outweigh other unfavorable ones, such as large trim changes, which will be discussed later.

SECTION IV

CONTROL FORCE CONSIDERATIONS

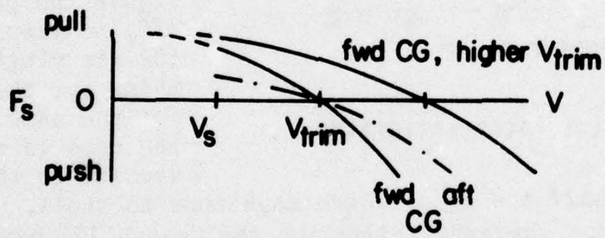
In this section several aspects of control force as they influence low speed operations are considered. The material is based largely upon the TASK 2 testing of seven airplanes, supplemented by in-flight simulation experiments with the variable-response airplane described in Appendix F.

A. BACKGROUND

Control "feel" in the form of a gradient of stick force with airspeed — pull force to slow from trim speed, push force to speed up — is universally regarded as a desirable flying quality, and in fact is required by both civil and military authorities (Reference 6 and 7). The question addressed here is to what degree such forces play a role in stall awareness and avoidance.

B. STICK FORCE vs V

Expected Variation. Most stability and control textbooks (Reference 9 for example) carry a theoretical development which leads to the finding that the variation of control force with speed for conventional, statically stable airplanes should go as shown in the sketch below:



The force variation depends on some built-in parameters such as control gearing, hinge moment and elevator effectiveness coefficients, and the square of the velocity. The intercept of the curve at V = 0 is a function of the stick-free static stability, and this varies mainly with center of gravity position (and secondarily with other factors such as power). At any rate, the gradient through trim steepens with forward CG movement, less power, or lower trim speed; flaps may or may not affect the slope, depending on the peculiarities of the aerodynamics.

Measured Variations. Some measured variations from the TASK 2 flight tests are shown in Figures IV-1, IV-2, and IV-3.

Before considering these results, the following points should be noted:

> In keeping with the purpose of providing background and orientation in the area of unintentional stalls, the measurements were purposely kept simple in style and scope, and were not intended to be a basis for checking on FAR compliance.

- For stick force and velocity measurements a hand-held force gauge and the standard airplane airspeed indicator were felt to be appropriate. In particular, indicated rather than calibrated airspeed was used, not only because calibrations for the many configurations tested would have been very time consuming and expensive to obtain, but also because the pilot's direct source of information is the indicator; it seems likely that his actions and judgment will usually be based on uncorrected instrument readings.
- Trim (zero stick force) speeds were usually chosen to correspond to a normally-used value; in some cases, as for the Cessna 182, the minimum attainable trim speed for the forward CG, power-off configuration was used throughout for uniformity even though the airplane could be trimmed to lower speeds under other conditions. The minimum speed points shown are at or very near the stall.

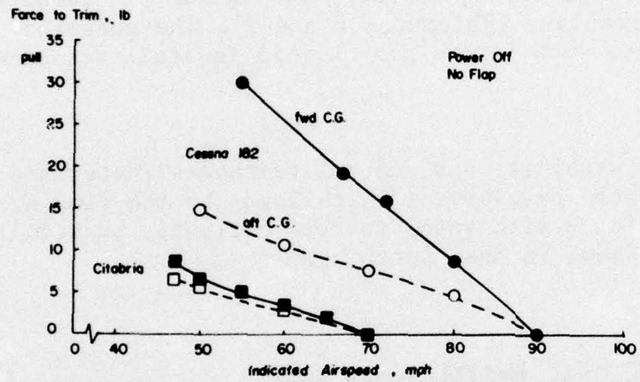


Figure IV-1. Stick Force Variations.

The Citabria, by contrast has a relatively low gradient and force to stall, and little variation with center of gravity position; the feel is qualitatively "spongey" compared to the 182.

Turning to Figure IV-2, the three Cessna airplanes in the program are compared. In the upper half of the figure the previous power-off, no flap points for the 182 are plotted along with those for the 177 and 150 for the same condition. The 150 case is seen to be similar to that of the 182, but with roughly half the stick force magnitude to stall.

Power-off force characteristics for the Cessna 177 have an unfamiliar look, both due to the small spread for forward and aft CG position and for the upward curvature. The latter is apparently not uncommon for airplanes such as this with stabilator and anti-servo tab. A steep gradient is in evidence and the force level to stall is again substantial.

The lower half of Figure IV-2 presents trim curves for the same three Cessnas, but for the other extreme condition of full power and full flap. Expected behavior is shown in the 177 case, with force levels remaining moderate. The other two show some peculiarities which warrant discussion.

In the case of the 150, both the gradient and the force to stall are drastically reduced. In fact, with aft CG, the airplane can't be trimmed to zero force at the previous 70 mph speed, and only two pounds of pull force will produce a stall; with forward CG the force to stall is still a relatively light 5 lb. Though stable, the gradient is so small as to provide little feel for speed changes.

With forward CG the full power, full flap Cessna 182 exhibits its normal, heavy feel. With an aft CG, however, the situation becomes a bit confused, as indicated by one data point at 48 mph with a possible range from 0 to 15 lb; the dotted line suggests a likely change with speed. The problem is one of large trim changes with sideslip, the airplane pitching up for a right slip and down for a left slip (there appears to be some real trim change, but the exact level measured here could be influenced by airspeed errors since the task involved a flap-down, high-power phenomenon, and once identified, it accounts for an observed problem in holding a precise climb speed in that configuration.

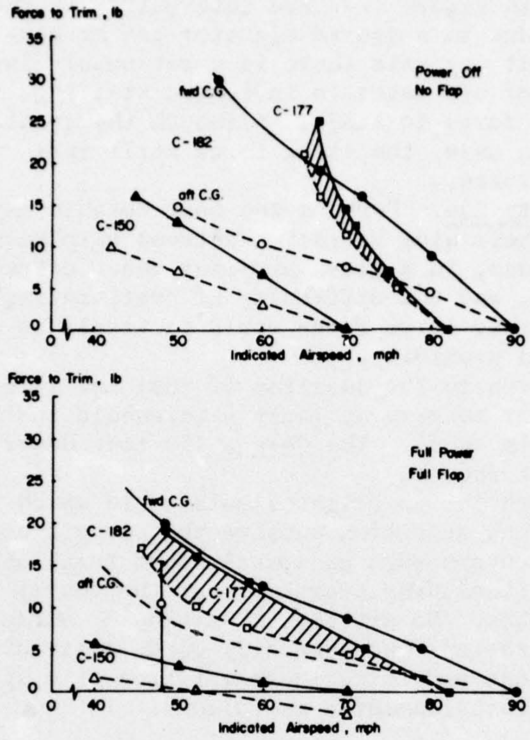


Figure IV-2. Stick Force Variations.

Figure IV-3 is the final one in the series and presents results for the Piper Cherokee 140 and the two Grumman American airplanes; together with the Cessna 150 they represent widely used trainers. Here the conditions have been chosen to display extreme combinations of power, flap, and center of gravity position. Again, the variation in the Cessna 150 curves is striking. The Cherokee displays modest changes, with fairly light stick force evident in the aft CG case.

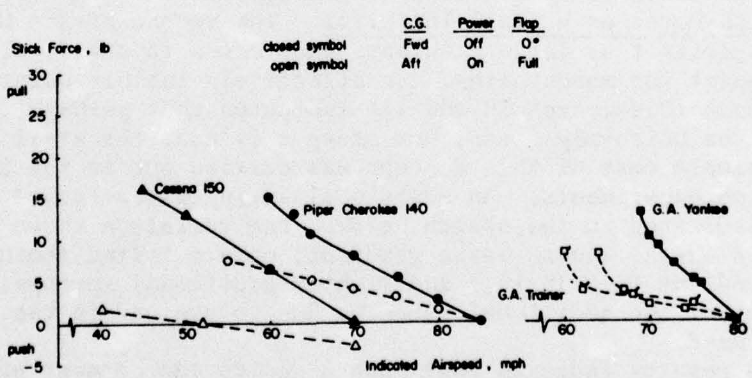


Figure IV-3. Stick Force Variations.

The Yankee and Trainer curves in Figure IV-3 are interesting in their upward curvature which is possibly due to a geared elevator tab or non-linearity in the control linkage. At any rate there is a reasonably large change between the power on and power off cases in indicated stalling speed as well as force gradient and force to stall. Although the gradient is initially shallow in the power-on case, the stick force still ends up being about the same as for the Cherokee.

Stick Force as a Stall Proximity Cue. Perhaps the most notable aspect of these force characteristics is their wide variation between airplanes and, especially in the Cessna 150 case, in a given airplane under different conditions. Given this variability, and the difficulty of "calibrating" the human pilot, it seems unlikely that stick force would in itself be a generally dependable cue as to stall proximity.

However, some attention was given to the question of just how large the force to stall has to be in order to give at least a threshold indication of being well away from the trim speed. The Cessna 150 test described above demonstrated that 2 lb was not enough.

An experiment was conducted with the in-flight simulator in which the evaluation pilot was asked to fly with attention outside the cockpit and stall the airplane from various maneuvers such as low-altitude turns about a point, turns onto final approach (including overshoots of the center line) and "stretched" final approaches. No artificial warning or buffet was available. The various configurations had generally good longitudinal handling qualities, but force gradient and force increment from trim speed to stall speed were varied. The pilots commented as follows:

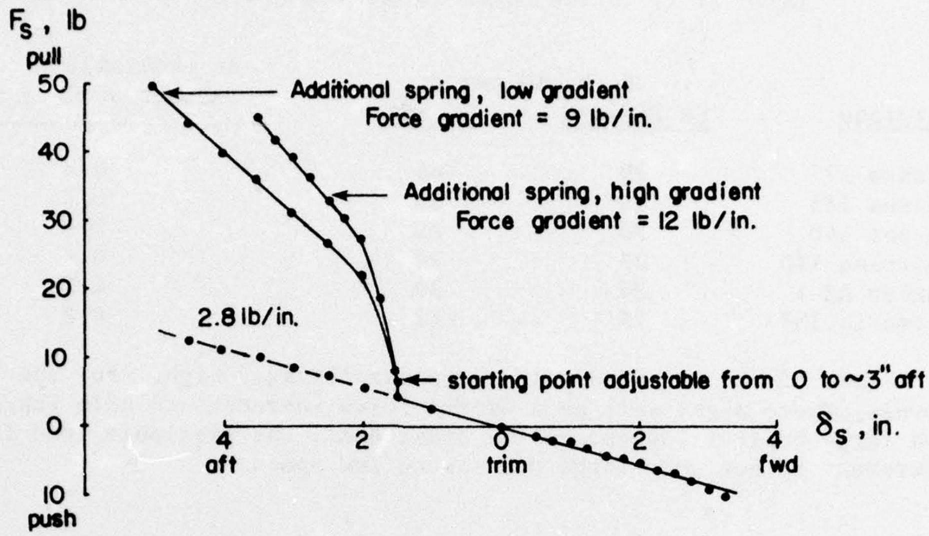
Force increment from trim to stall	Comment
2-3 lb	Very light, unsatisfactory cue
10 lb	Good level, satisfactory
17 lb	Heavy, satisfactory

This represents rather limited evidence, but apparently the threshold for force indication is somewhere in the neighborhood of 10 lb.

Stick Force as a Stall Inhibitor. The record of the Cessna 182 at least suggests that large gradients and forces to stall, although perhaps not pleasant for maneuvering, can effectively inhibit unintentional stalling. Recent work (References 10 and 11) indicates that perhaps the force gradient need not be uniformly steep, but steep only near the stall angle of attack.

A simple test of this concept was carried out in the in-flight simulation experiments. An additional spring was attached to the feel system as indicated in the sketch below. The variation shown has a rather light 2.8 lb/in. linear basic gradient; others tested featured a steeper basic gradient (4.8 lb/in.) and lighter additional springs. The nonlinear character of the additional force is due to preload in the short coil springs used.

The results indicate that such a device can be most effective as a deterrent, but the change in gradient must be quite sharp and large, almost in the nature of a "yielding stop"; the variations in the sketch gave this impression. Encountering the change in gradient during the landing was initially quite objectionable, but became less so with practice.



Although the concept has merit, the simple spring-in-the-system approach may not prove practical due to the presence of large and conflicting trim changes from power, flaps, CG shift and ground effect.

C. STICK FORCE TO MANEUVER

Although stick force per g is normally considered to be a handling factor in cruise and relatively high speed maneuvering, measurements of this parameter were made in connection with TASK 2 to determine if it held any significance in the low speed maneuvering case. A sample of the data is shown in the sketch below, and measured values for the power off, flap down case are given in Table IV-1.

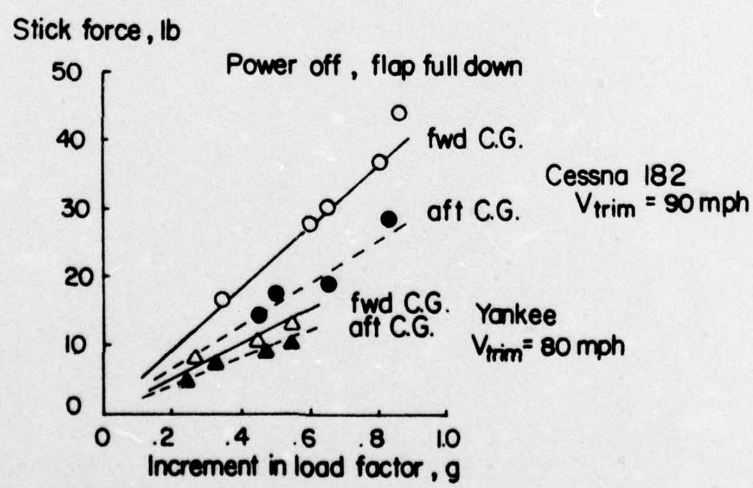


TABLE IV-1. STICK FORCE TO MANEUVER AT APPROACH SPEED

Airplane	F_s/n, lb per g CG forward	CG aft	Δn available (abrupt pull-up at V_{trim})
Cessna 177	70	65	0.7
Cessna 182	48	30	0.7
Cessna 150	30	25	0.8
Cherokee 140	25	20	0.8
Yankee AA-1	24	20	0.5
Citabria 150	15	12	0.8

Some of the measured values are surprisingly high. For the larger levels, there might well be a useful force increment to help inhibit sudden large control inputs; on the other hand, the available load factor increment is not very large due to the low speed.

SECTION V

TRIM CHANGES

Nose-up trim changes due to power or flap are obvious candidates as factors which might induce an unintentional stall. Table V-1 shows the results of measurements taken on the seven airplanes of TASK 2.

TABLE V-1. STICK FORCE TO HOLD TRIM SPEED, lb.
F ≡ PUSH, A ≡ PULL

Airplane	Power Off → Max	Flap 0^o → Full	Sideslip Left	Sideslip Right
Cessna 182	36 F	34 F	12 A	15 F
Cessna 177	26 F	16 F	9 F	6 A (Power On)
			3 F	5 F (Power Off)
Cessna 150	12 F	11 F	10 F	10 F (Flap 0^o)
			2 A	2 A (Flap 40^o)
Citabria 150	12 F	(Unflapped)	2 A	1.5 F
G.A. Trainer	8 F	3 A		
Cherokee 140	7 F	2.5 A	8 F	7.5 A
G.A. Yankee	6.5 F	1 A	4 A	6 A

The force levels are seen to be quite large in some cases, requiring prompt trimming action. Some interesting, though not very significant, effects of sideslip are evident, including change in force with direction of sideslip, a factor mentioned in the previous section in connection with the Cessna 182 trim curves.

Not indicated in the table but observed in flight is the fact that the trim changes with either power or flap in the Cessna airplanes are of sufficient magnitude to cause the airplane to stall itself if left unattended. However, only a part of the force shown had to be applied to prevent the stall.

Trim changes due to power were explored briefly in the in-flight simulation phase in connection with aborted approaches and touch-and-go landings, with the findings that almost any level requiring trim action is considered annoying. Forces in the neighborhood of 30 lb were definitely objectionable. However, if adequate control power was available to control the flight path, and if the forces could be trimmed off in a timely manner, even large trim changes were judged to be tolerable.

Thus the significance of trim changes in the stall accident picture remains unclear, partly because the airplane with the best accident record exhibits the largest effects. Despite the lack of hard evidence, however, it seems obvious that a large nose-up trim change occurring during a moment of inattention could lead to a stall. Also, factors causing the trim change could result in reduced nose-down control power being available for recovery (as discussed in Section II with respect to the Cessna 150). All in all, it would seem desirable to minimize trim changes if possible.

SECTION VI

STALL WARNING

A. BACKGROUND

The subject of stall warning is clearly central to the study of inadvertent stalls. It was touched upon in the accident analysis of Section II, where it was pointed out that one-third of the stall accidents and one-half of the spin accidents for which data are available involved airplanes which did not have stall warning indicators installed (conversely, two-thirds of the airplanes in stall accidents and one-half of those in spin accidents apparently did have such devices). One way to interpret this finding is that some accidents might have been avoided if a stall warning had been installed in all cases; another interpretation suggests that since accidents continue to happen with standard systems installed, consideration should be given to their improvement.

Federal Airworthiness Standards (Reference 6, § 23.207) call for clear and distinctive stall warning in any normal configuration, in both straight and turning flight. The warning may be either natural (aerodynamic buffet) or artificial, and must provide a speed margin before stall of not less than 5 knots or more than 10 knots (or 15% of stall speed if that is greater).

Despite the seeming clarity of the regulation, the continuing accident history (including military cases) strongly suggests that the warning of impending stall is not always getting to the pilot in a useful form or time frame. It is not as though the subject has escaped serious attention; the amount of literature directly related to stall warning and warning devices is impressive. Some 30 items of the Bibliography - entries 49 through 77 - address the subject, and indicate that artificial warning systems were in use as early as 1938 (Reference 12), and that research on new devices continues at the present time (References 13 and 14).

B. MEASURED STALL MARGINS

The stall warning observed in the course of the TASK 2 testing was generally unimpressive. All seven airplanes with the exception of the Citabria had artificial warning devices; all gave an aural signal except for the Piper Cherokee 140 which utilized a panel light. In terms of sound quality, the aural warnings in the Grumman American airplanes were the only ones which came through with impressive loudness and clarity; in the Cessnas tested, the sound tended to be soft, intermittent, uninteresting, and, on occasion, absent.

The warning margins observed are shown in the following table.

TABLE VI-1. STALL WARNING MARGINS
Increment Above Indicated Stall Speed, mph

Airplane	Power Setting	Flap Up Horn	Flap Up Buffet	Flap Down Horn	Flap Down Buffet
Cessna 182	Off	24	-	22	3
	On	12	12	22	0
Cessna 177	Off	12	-	10	-
	On	10	2	10	-
Cessna 150	Off	10	-	(?)	-
	On	7	-	(?)	-
Citabria 150	Off	-	-	-	-
	On	-	8	-	-
Cherokee 140	Off	17	4	3	0
(Panel Light)	On	16	2	10	0
G.A. Yankee	Off	5	2	1	1
	On	4	1	5	1
G.A. Trainer	Off	10	2	Not Recorded	
	On	7	0	2	2

Great variability is apparent between airplanes and between configurations for a given model. The warning on the Cessna 182 is so premature that it is easily ignored; on the other hand, as noted elsewhere, the stall is docile and usually requires considerable physical effort to produce.

Buffet, if present at all, usually occurred too close to the stall to be useful.

C. DESIRABLE SPEED AND TIME MARGINS

The in-flight simulation work (TASK 3) produced the following results which relate to stall warning:

Speed and Time Margin. Pilot commentary indicated the following with regard to stall warning margin for configurations with satisfactory feel characteristics (Section IV) which were trimmed for pattern operations at 75-80 knots and stalled at 60-62 knots:

Stall Warning Horn Speed Margin	Comment
2-3 knots	Too small
4-5 knots	Marginal
6-7 knots	Acceptable

These results are for slow to moderate (3 kt/sec) decelerations, both in straight flight and in turns. One pilot volunteered the comment in one instance that the time interval between warning and stall was simply too short (in that particular run it was between one and two seconds). The time margin aspect unfortunately could not be pursued at any length, but there is other recent work (Reference 15) which suggests that it is a significant factor in need of systematic study.

D. HORNS, STICK SHAKERS, AND ANGLE OF ATTACK INDICATORS

The in-flight simulator was equipped with selectable horn and stick shaker warning systems, and pilots were asked to comment on their relative effectiveness for various configurations and situations. The results

simply reinforced the already-known (Reference 16 , for example) strong pilot preference for the tactile cue provided by the shaker system.

Angle of attack indicators were available in three styles: dial type in upper left hand corner of the panel, calibrated in % of maximum lift; Navy-style vertical indexer with "chevrons" and "donut," mounted above the panel in the line of vision; and a Safe Flight horizontally-mounted slow-fast speed control unit also mounted above the panel in the line of sight (see Appendix F).

The evaluation pilots were allowed to sample these devices, and although again the results are not extensive, some trends may be noted:

- General aviation pilots are usually unfamiliar with such equipment, and a period of adjustment is required. Any of the three could be utilized effectively with practice.
- As warning devices, such indicators have the shortcoming of requiring the pilot to look straight ahead or even down at the panel.
- After considerable flying with the combination, one pilot felt that either a horn or stick shaker plus the dial-type unit gave the most effective warning. The horn or shaker furnished a proximity cue, and the indicator provided useful information on whether or not the angle of attack was increasing further, holding steady, or decreasing. This was most helpful in recovery from maneuvers in which large pitch attitude had been reached.

In summary, despite past efforts, the subject of stall warning still appears to warrant a good deal of serious work.

SECTION VII

PERFORMANCE AS A FACTOR

Climb and descent performance of the seven TASK 2 airplanes were measured to determine whether or not an undue sensitivity to speed existed; in particular, it has been suggested that if performance falls off very rapidly as speed decreases, a pilot might be induced to enter a mush condition. As in other TASK 2 measurements, the experiments were designed simply to illuminate this area of concern, and not to provide data indicative of absolute climb performance.

Figure VII-1 presents the results in terms of a ratio between the rate of climb and the maximum observed, or in the power-off case, the ratio between rate of descent and the minimum rate observed. The rates themselves were determined by recording the altitude increment traversed in a steady climb or descent of at least one minute duration. Reasonably smooth, low altitude conditions were sought, but since absolute performance was not of primary interest, the data were not corrected for weight or non-standard conditions. Open symbols represent flap-up cases, darkened symbols flap full down. The small triangles on the plot denote indicated stall speed.

The results indicate a general lack of sensitivity to being moderately off the most favorable speed; even errors as large as 10 mph seldom reduce the rate of climb more than 10%. In most cases the stall must be approached closely before a very large performance decrement is noted.

Flap drag varied notably from airplane to airplane, but only in the case of the Cessna 150 was there a drastic climb performance reduction. However, the accident record suggests that this is not a particularly significant factor in this case.

Finally, the flap down descent cases exhibit an interesting lack of "backside of the thrust-required curve" characteristic, with descent rate tending to lessen with decreasing speed almost to the stall in most instances.

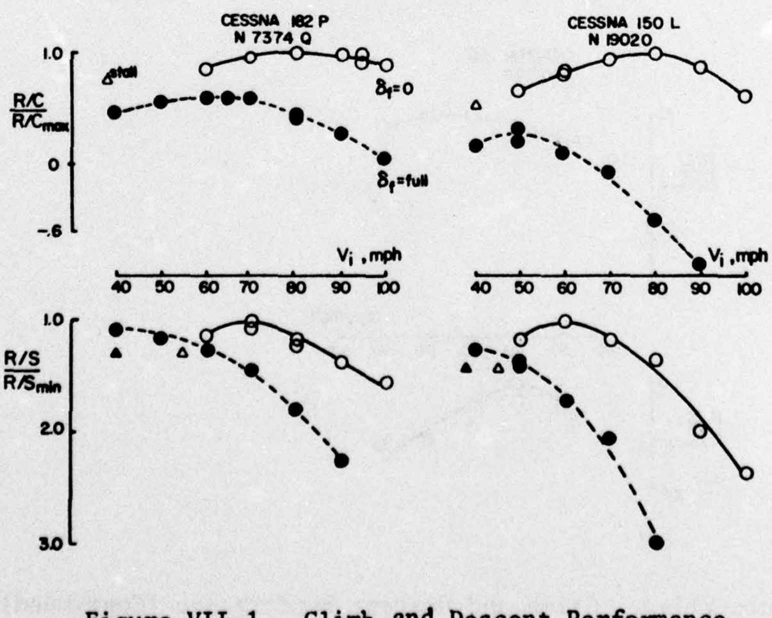


Figure VII-1. Climb and Descent Performance.

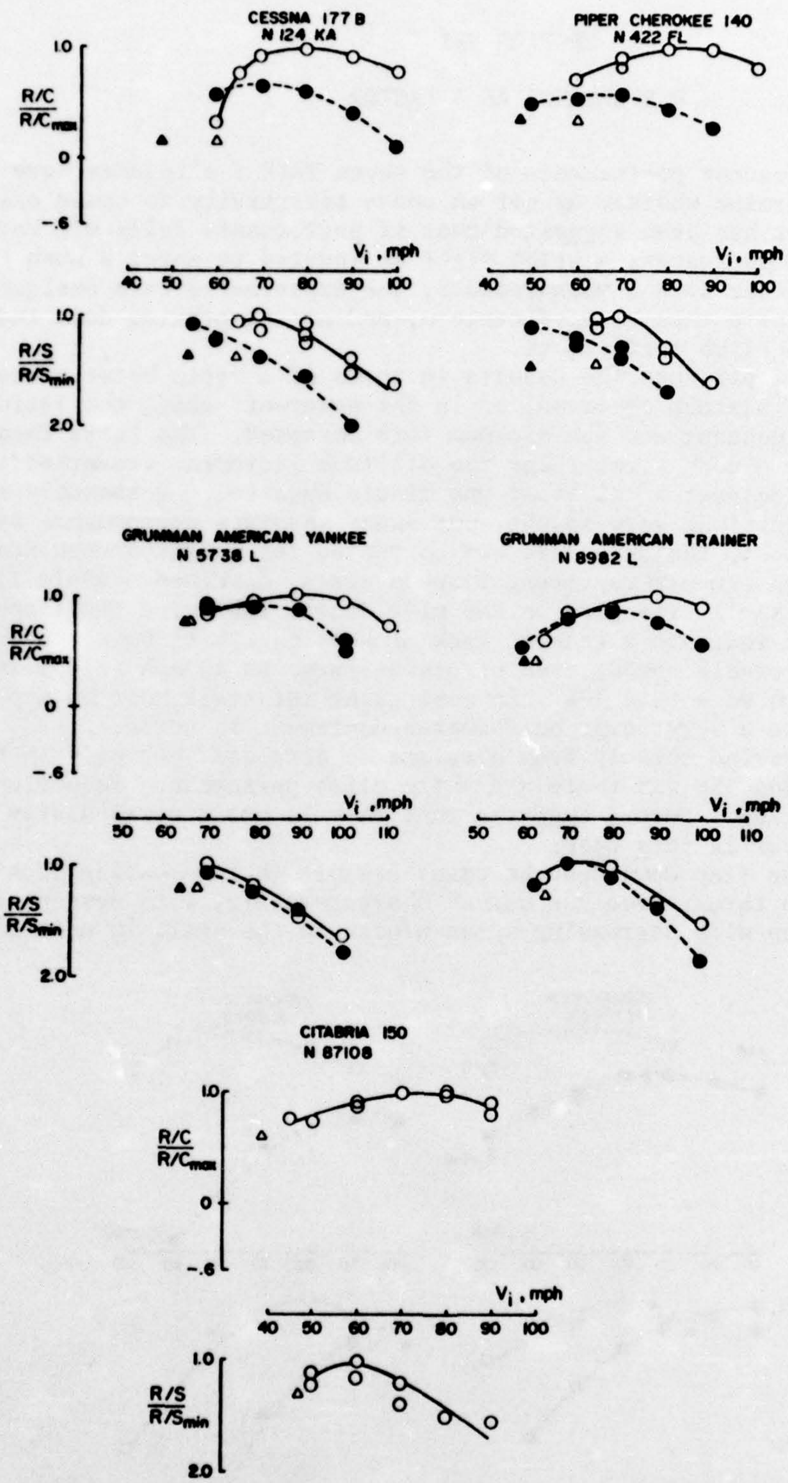


Figure VII-1. Climb and Descent Performance (Continued).

SECTION VIII

THE OUTLOOK FOR PROGRESS

A. AWARENESS OF THE PROBLEMS

Recognition that a problem truly exists is a necessary first step in improving the stall-related accident record; this awareness has been sharpened by the NTSB survey (Reference 4) and reports of military and NASA research activities (References 3 and 5, for example). Hopefully, the present study will serve to bring the problem into better focus and suggest areas which might benefit from further research activity.

The record, as summarized in Section II, is clearly not good. Particularly disturbing are the observed large differences between accident rates for various airplanes, mainly because such differences are not altogether explainable at this point. Although the flight test phase confirmed that substantial differences in flying qualities exist between various makes and models (and between various configurations and flight conditions for a given airplane), it has not been established whether these rank in importance with usage factors such as type of flying and pilot experience. Thus a good deal of work remains to be done in the area of accident analysis for individual makes and models, much in the style of the analysis of the overall group statistics performed for this report, with added attention to details available in the complete files (but not coded on the present tapes). Also, it appears in retrospect that the present analysis may have unduly emphasized fatal accidents, and any new work should give equal attention to the extraction of pertinent information from non-fatal cases as well.

With additional effort in the accident analysis area, it will be possible to assemble a much more detailed picture of the stall-related accident for individual airplanes, and this in turn will enhance our feeling for the relative importance of usage/piloting factors and airplane characteristics.

B. IMPROVING THE PILOT

Although significant gaps exist in the understanding of stall-related accidents, it is possible, on the basis of the work thus far, to suggest several areas which warrant immediate consideration. The extremely high incidence of citation of the pilot as a cause or factor in such accidents (see Section II-B) naturally tends to focus attention on training and proficiency; indeed, industry spokemen tend to emphasize pilot involvement to the point of virtually excluding mention of the airplane itself (Reference 17).

There is evidence which suggests that training in itself cannot eliminate the stall-related accident. Even in the military, with the most extensive training, both initial and recurrent, and where the hazards of high angle of attack situations can be reviewed on a flight-by-flight briefing basis, the stall accident continues to occur. Intensive efforts were put forth in the late 1930's and 1940's to educate pilots to the hazards of the stallable and spinnable airplanes of that time (Reference 18), but it took a new generation of airplane designs to achieve a significant

reduction in stall-related accidents (Reference 19). However, it would appear useful to consider what might be done to take advantage of an enhanced awareness of the stall accident problem with the airplanes presently in the general aviation fleet.

In Depth Training and Open Ratings. The present study suggests that the modern single engine lightplane is probably more complex in terms of stall characteristics than most pilots realize. The observed variations between various makes and models, and between configurations in a given airplane are rather striking, yet the handbook information available to the pilot usually describes the stall behavior simply as "normal." It would appear to be both highly advisable and possible to do the following:

- Make the student pilot aware that all airplanes don't necessarily have the same stall behavior as the one in which he is learning.
- In the course of instruction or check out, require the pilot to be exposed to the complete range of possible behavior (including extremes of center of gravity position).
- Provide a detailed discussion of stall characteristics (and other flight characteristics as well) in a standardized operator's manual.

Although the idea will undoubtedly be resisted in many quarters, the observed variability in flight characteristics, along with operating complexities and lack of cockpit standardization, tend to suggest that the present system of "open" ratings (SEL or all single engine landplanes, for example) should perhaps be replaced with a system which would insure a pilot's being completely familiar with each airplane he flies.

Recurrent Training. With the biennial flight review now established, it seems worthwhile to suggest that it could be used as an avenue of communication to make each pilot aware of the general aviation accident picture, including problems peculiar to the particular airplanes he flies or expects to fly. In the flight phase of the review stalls should receive special emphasis.

C. IMPROVING THE AIRPLANE

It is often suggested that the most effective way of eliminating the stall-related accident would be to make all airplanes stall-proof. This is unrealistic of course, since stalling is sometimes demanded by the mission (training or acrobatics, for example) or by the airplane configuration (many tailwheel landing gear airplanes must be either full-stall landed or "wheel-landed" to prevent bouncing); and moreover, making an airplane stall-proof under all conditions without compromising performance, utility or control system simplicity is invariably difficult.

Recent and ongoing research does indicate, however, that the role of the airframe design in the accident picture bears careful examination (Reference 20). Some avenues for improvement are discussed below:

Improved Stall Warning and Warning Systems. The discussion of Section VI implies quite strongly that much work is needed in the area of stall warning and stall warning systems. In particular, the question of whether or not both time and speed margins are necessary should be answered with definitive experiments, preferably utilizing in-flight simulation so as to explore a usefully wide range of characteristics in a realistic environment.

The superiority of buffet or tactile "buffet-like," warning over aural or visual warning is already well known, and suggests that every reasonable effort should be made during prototype development to provide natural aerodynamic buffeting; also development and application of low-cost, reliable stick shaker devices would appear desirable.

Improved Aerodynamics. New airfoil and wing research holds promise for improved stall characteristics in future designs. The art of optimizing airfoils by use of digital computing is progressing rapidly, and several recent European designs have demonstrated "soft-stalling" characteristics intentionally integrated into the airfoils.

Reference 21 covers the progress of some recent wing design work in this country; an unconventional aerodynamic approach to stall and spin-suppression utilizing a canard configuration is discussed in Reference 22.

Larger Stall Margins with Flight Path Spoilers. Recent experiments with flight path spoilers integrated with the power control reported in Reference 23 indicated that use of such devices allows the airplane to be flown at higher than normal stall margins without suffering landing performance penalties. Also, the need for large flap deflections to steepen the glide path is removed, thus lessening trim changes associated with flap and power and making the go-around maneuver less critical and less conducive to unintentional stalls.

It appears likely that utilization of such devices could lessen the incidence of stall accidents in the approach and go-around flight phases as well as improve the landing accident record. The concept has been successfully demonstrated, but not yet applied to production airplanes.

Control Power Limiting. Limiting pitch control power to a level which makes it difficult or impossible to completely stall the airplane is an approach to the stall problem which is receiving renewed attention after a lapse of many years; this method of stall suppression was seriously advocated some years ago and saw successful use in the Ercoupe and General Skyfarer designs (Reference 19 covers some of the history) and also in a less extreme form in the Stinson 108 and Bellanca Crusair.

The problem is admittedly much more difficult in more recent designs with high power, large flaps, and most significantly, large center of gravity range. However, it is possible to conceive of a system having stops which are adjusted as a function of throttle setting, flap deflection, and trim tab setting, thus providing appropriate maximum elevator deflection under all inflight conditions (the trim control would account for center of gravity position, but unless properly set before takeoff might permit excess up-elevator in that phase).

Other more complex systems which effectively limit the available control power have already been mentioned (References 10 and 11).

Another approach out of the past is that used on the Culver "V " (Reference 24) designed by A. Mooney and produced in the 1946-1948 period; in this case the pilot's stick controlled a very small elevator that permitted only limited maneuvering about a trim point. The trim point was adjustable, of course, and utilized an interconnected stabilizer and flap.

It will probably always be desirable to design a stall and perhaps a spin capability into some airplanes for purposes of training or sport acrobatics; however, it might be seriously questioned again, as it has been in the past, whether or not the airplane which is to be used almost exclusively for cross-country transportation needs ever to be completely stalled.

The use of tricycle gear makes it unnecessary for landing, and the small reduction in attainable lift coefficient inherent in the control-limiting concept does not usually result in large performance penalties (especially if use of advanced airfoils and flight path spoilers is contemplated). For non-aerobatic airplanes, control power limiting possibly represents the most promising method of reducing stall-related accidents.

SECTION IX

CONCLUSIONS

1. A detailed statistical analysis of stall and mush accidents for the period 1965-1973 allows the following observations to be made:

   a. With regard to the circumstances of occurrence:

      - Stall and mush accidents happen most often in personal flying (non-commercial pleasure or practice), followed by instructional and business/executive flying.
      - Nearly half of all stall and mush accidents happen in the "in-flight" phase, with the remainder divided between takeoff and landing phases. Most of the fatal in-flight phase accidents are associated with acrobatics, buzzing, and low passes; turning prior to stall is involved in a high proportion of the cases.
      - Stall and mush accidents happen almost exclusively in daylight and in good weather.
      - The statistics confirm that stall and mush accidents are most likely to happen to pilots with low total time and low time in type. The role of recency of experience was not evaluated.

   b. With regard to cause:

      - The pilot in command is cited as cause in nearly all stall and mush accidents.
      - The most common citation is, "Pilot in command failed to obtain or maintain flying speed."

   c. With regard to airplane make and model:

      - For a group of 31 single engine airplanes, stall/mush accident rates differ by as much as a factor of 20 between best and worst cases.
      - When ranked according to the accident statistics, older (especially pre-1940) designs consistently show up poorly compared to post-World War II airplanes, with a few recent exceptions.

2. Flight tests of seven different airplanes revealed the following with regard to general high angle of attack handling and stall characteristics:

   a. With forward center of gravity, low power, and no flap, generally good behavior was observed for coordinated (no sideslip) stalls. In some cases a complete stall could not be reached, especially in a turn; at worst a pitch break could be obtained but rolling tendencies were controllable and normal recovery technique sufficed.
   b. Rearward (aft limit) C.G., high (maximum) power, and full flap deflection, singly or in combination tended to degrade the stall behavior. Among the notable effects were the following:

- Lowered stick force gradients compared to (a), in some cases markedly so.
- More control power than that required to reach a stall was available in most cases.
- Rolling and yawing tendencies could be pronounced at the stall, particularly if up-elevator motion was continued. Vigorous use of aileron and rudder often were needed to prevent departure.
- Because of cumulative trim changes, one case of barely adequate down-elevator power for recovery was noted.

c. Uncoordinated (rudder allowed to float) stalls almost always result in first yaw, then roll before pitching break could be observed. This usually cannot be countered with aileron, particularly in the critical cases (high power, aft C.G., flap down).

3. With regard to elevator control force as a factor in providing feel and stall deterrence, the following observations are pertinent:

   - Control force versus velocity characteristics and force to stall varied widely between the airplanes tested. Although the gradients measured were stable in all cases, force levels ranged from a qualitative "very heavy" to "very light."
   - For a given airplane, the force characteristics were highly dependent upon power setting, flap position, and center of gravity position. In some cases the differences between extreme conditions were striking (15 lb pull to stall in one configuration, 2 lb in another); in others, forces changed but remained relatively high at all times.
   - For some airplanes, the measured force gradients are sensitive to sideslipping, and may be different for right and left slips.
   - Owing to the large variations observable in a given airplane, and the difficulty in "calibrating" the pilot, the absolute level of stick force in itself is likely to be unreliable as an indicator of stall proximity; however, large force levels (i.e., in the neighborhood of 20 lb or more) tend to inhibit stalling if they must be held for any appreciable length of time.
   - In-flight simulator experiments tended to confirm that forces to stall in the neighborhood of 5 lb are qualitatively "light," and require care in handling, particularly in the absence of stall warning.
   - It has been suggested that a marked increase in stick force for the last portion of up-elevator travel would provide a useful stall deterrent; a simulation indicated that in order to be effective, the change had to be quite sharp, and the ensuing gradient relatively large.

4. The significance of trim changes in the stall accident remains unclear, but the following points may be noted:

   - Very large nose-up trim changes with either power or flap deflection (more than 30 lb push required to hold trim speed) were measured in one case; if left unattended, the airplane would stall itself. However, in view of this airplane's very good accident record, this is apparently not a significant factor.

- In-flight simulation indicated that even small power-induced trim changes are annoying, but reasonably large magnitudes can be tolerated if sufficient control power is available to prevent serious changes in attitude or flight path, and if the forces can be trimmed off quickly.
- Despite the lack of compelling evidence based on observed handling problems, the possibility of a nose-up trim change causing a stall during a moment of inattention is bothersome; also, the factors causing the trim change could contribute to a problem of having excess elevator control power at the stall. For both of these reasons it appears desirable to minimize trim changes, or to introduce favorable ones.

5. Stall warning is clearly an important factor in the stall accident picture. The results of this permit the following observations:

   - A large proportion of stall/mush (and spin) accidents happen in airplanes without artificial stall warning systems. One interpretation of this result is that some accidents might have been avoided if such a device had been installed; another suggests that since accidents continue to happen even with stall warning systems installed, consideration should be given to their improvement.
   - Stall warning on the test airplanes was generally not impressive; the warning margin varied greatly with configuration, and was often so premature as to invite disregard. Aerodynamic buffet, if present at all, often happened too close to the stall to be useful.
   - A time margin as well as a speed margin may be desirable; this was qualitatively reinforced in the simulation experiments, although the testing was not extensive enough to define the minimum time needed.
   - The in-flight simulations found pilots definitely preferring tactile (stick shaker) over aural (horn) warning; this simply adds to similar results produced elsewhere.
   - Angle of attack indicators as warning devices were faulted for requiring the pilot to look inside the cockpit (or at least ahead over the panel), but when used in conjunction with a horn or shaker, they provide a very useful indication of whether the situation was progressing into or away from the stall.

6. Maximum power climb and power-off descent performance were measured on the test aircraft to determine whether or not an undue sensitivity to speed existed; in particular, whether slowing the airplane below normal climb speed could result in such a rapid loss of climb rate (or increase in sink rate) as to induce the pilot to enter a mushing or stalled condition. The findings including the following:

   - None of the airplanes showed an undue tendency in this respect; in fact, the power-off, flap down cases consistently showed little or no "backside" characteristic.
   - One airplane did show a very large loss of climb performance with full flap. However, its accident record does not suggest that this is a strong factor.

SECTION X

SUMMARY OBSERVATIONS

1. The stall-related accident problem is clearly a serious one, and the large differences between accident rates for various airplanes are disturbing, partly because they are not altogether explainable at this point. It would be very helpful to know the accident patterns, causes, and factors for individual makes and models as well as for the group as a whole; for the most complete picture, this should be assembled by examining the accident files as well as the coded tapes.

2. The "simple" single engine lightplane is possibly more complex and varies more from model to model in terms of flight characteristics than many pilots appreciate. It would appear worthwhile to determine whether or not present-day training practice addresses the subject with sufficient depth to justify continued use of "open" pilot ratings.

3. Several avenues for improving the stall-related accident record by improving the airplane are available. In brief, they include the following:

   - Use of flight path spoilers to permit the airplane to be flown with larger stall margins without suffering landing performance penalties. This might also allow use of simpler, small-deflection flaps which would help alleviate trim change and control power problems. The concept has been successfully demonstrated, but not applied to production airplanes.
   - Application of recent airfoil and wing research. This holds considerable promise for better stall behavior and more straightforward design procedures.
   - Renewed attention to stall warning requirements and stall warning systems. In particular, the question of time margin prior to stall should be addressed.
   - Reexamination of the question (or possibility) of limiting elevator control power for modern lightplane configurations. For non-acrobatic airplanes this may be a most reasonable solution to problems of inadvertant stalls.

SECTION XI

REFERENCES

1. "The Papers of Wilbur and Orville Wright," edited by Marvin McFarland, with Notes of Commentary and Appendices, New York, McGraw-Hill Company, 1953. Two vols.

2. "First Rebuttal Deposition," "The Wright Company vs the Herring-Curtiss Company and Glenn H. Curtiss, Complainant's Record, United States District Court, Western District of New York, 1912, pp 473-614.

3. "Stall/Spin Problems of Military Aircraft," AGARD Conference Proceedings No. 199, June 1976.

4. "Special Study - General Aviation Stall/Spin Accidents 1967-1969," NTSB Report AAS-72-8, September 1972.

5. Bowman, J. S., Jr., "Summary of Spin Technology as Related to Light General Aviation Airplanes," NASA TND-6575.

6. "Airworthiness Standards: Normal, Utility, and Acrobatic Category Airplanes," Federal Aviation Regulations, Part 23, June 1974.

7. Anon: "Military Specification, Flying Qualities of Piloted Airplanes, MIL-F-8785B(ASG), 7 August 1969.

8. Wimpenny, J. C.: "Low-Speed Stalling Characteristics," AGARD Report 356, April 1961.

9. Seckel, E.: Stability and Control of Airplanes and Helicopters, Academic Press, New York, 1964.

10. Chevalier, H. and Brusse, J. C.: "A Stall/Spin Prevention Device for General-Aviation Aircraft," SAE Paper No. 730333, 1973.

11. Chevalier, H. L.: "Aerodynamic Spoiler for Preventing Airplane Stall/Spin Type Accidents," Federal Aviation Administration Report No. FAA-RD-75-21, December 1974.

12. Thompson, F. L.: "NACA Stall Warning Indicator," NACA Report No. TN 670, October 1938.

13. Gilson, R. D. and Fenton, R. W.: "Development of a Stall Deterrent Device for Small Airplanes," Federal Aviation Administration Report No. FAA-RD-75-53, June 1975.

14. Bennett, G. and Owens, J. K.: "Flight Test of a Stall Sensor and Evaluation of its Application to an Aircraft Stall Deterrent System Using the NASA LRC General Aviation Simulator," Mississippi State University Report, March 1976.

15. Scott, B.: "Experimentation and Evaluation of Improved Stall Warning Equipment Phase II," Federal Aviation Administration Report No. FAA-TD-73-179, May 1974.

16. Ontiveros, R. J.: "Experimentation and Evaluation of Improved Stall Warning Equipment," Federal Aviation Administration Report No. NA-69-35, December 1969.

17. "Safety Facts & Figures - 1976" General Aviation Manufacturers Association, 1976.

18. Collins, L.: "Safety In Flying," Air Facts, Vol. 6, No. 7, July 1943.

19. Collins, L.: "V-S Day," Air Facts, Vol. 8, No. 6, June 1945.

20. Anderson, S. B.: "Design Considerations for Stall/Spin Avoidance," General Aviation Aircraft Safety," pp. 59-76, Federal Aviation Administration Report No. FAA-RD-74-154, October 1974.

21. Kroeger, R. A. and Feistel, T. W.: "Reduction of Stall-Spin Entry Tendencies through Wing Design," SAE Paper No. 760481, 1976.

22. Rutan, B.: "Aerodynamic Design Approach to the Stall/Spin Problem - The Vari Viggen," SAE Paper No. 740391, 1974.

23. Olcott, J. W., Seckel, E., and Ellis, D. R.: "Analysis and Flight Evaluation of a Small, Fixed-Wing Aircraft Equipped with Hinged-Plate Spoilers," ARAP, Princeton, N. J., Report 233. NASA CR- ,1977.

24. Collins, L.: "Culver V," Air Facts, Vol. 9, No. 8, August 1946.

APPENDIX A

AN ANALYSIS OF SINGLE-ENGINE LIGHTPLANE STALL ACCIDENTS (1965-1973)*

This section contains an analysis of stall-related accidents for the nine-year period 1965 through 1973. The primary emphasis is on "stall" and "mush" accidents, with "spin" and "spiral" types not being considered in detail (see Appendix B for definition of accident types, and Reference A1 for a more extensive treatment of spin and spiral accidents).

The study is limited to domestic accidents of U.S.-registered aircraft; no air carrier or military accidents are covered. Only fixed-wing power planes with one or two engines are considered, with statistical summaries for individual make and model formed only for single-engine airplanes. Within the above limitations, 41, 577 accidents were subject to review, of which 4,783 were of the stall, spin, spiral, or mush types. For purposes of analysis, crop control accidents were excluded, unless otherwise noted.

A statistical review of 31 aircraft (by make and model) was undertaken, selected on the following basis:

- Single-engine, fixed-wing configuration.
- Not primarily used for crop control.
- At least 500 active aircraft registered in 1973.

These 31 aircraft plus five summary groups were assigned "group numbers" from 1 through 36 (see Appendix C for listing). Selected results are given for these groups, with the most detailed attention being placed on "Group 32," which encompasses the 31 selected aircraft. For "Group 32," 30,606 accidents were available for analysis, or about three-fourths of the total 41,577. Of these, 3,467 were due to stall, mush, spin, or spiral; in statistical terms this is a large data base.

The data for the analyses were obtained from two sources:

- NTSB accident records, primarily from coded magnetic tapes.
- FAA estimates of hours flown for each make and model.

It is important to note that the NTSB coded data are not always complete. Most of the important items - such as accident type and cause - are considered mandatory entries on the tapes; certain others - such as runway length and altitude - are optical. Thus quite often statistics must be formed on the basis of reported data rather than on data for all accidents. The accident count itself is believed to be accurate but the details themselves depend upon the quality of the investigation and reporting; hopefully, the large data base will tend to smooth out the anomalies of individual accidents.

Accident rate data (accidents per 100,000 flight hours is the usual definition) are directly dependent upon the FAA estimates. These are primarily based upon owner/operator estimates, and although probably not exact, it seems reasonable to assume that there are no large differences

*Based on material prepared under subcontract by Brent W. Silver, Aircraft Safety Consultants, Inc., Palo Alto, Ca.

in reporting between various airplane makes and models.

SUMMARY GROUP RESULTS

Of the aircraft groups listed in Appendix C, the following five are "summary groups" and will be covered briefly before considering the 31-airplane Group 32 in detail:

Group 32 - Thirty-one single engine airplanes, no crop control accidents.
Group 33 - Crop control accidents only for Group 32 airplanes.
Group 34 - All general aviation fixed-wing aircraft, one or two engines.
Group 35 - All general aviation fixed-wing single engine aircraft.
Group 36 - All general aviation fixed-wing twin-engine aircraft.

The NTSB Stall/Spin Study (Reference A2) found that 22% of fatal accidents were due to stall or spin during 1967-1969. For Group 34 (1967-1973) the precentage is the same. When fatal spiral and mush accidents are added, the percentage grows slightly, to 24.2%. If both first and second accident types are included, then stall, spin, spiral, and mush account for 30.8% of all fatal accidents. These statistics vary only slightly over each of the nine years of the study.

Table A1 contains the accident results for each of the five summary groups. Accident types are arranged by columns, with the last column being a total of all accidents, whether stall-related or not. The percentages shown are based on this total. For each group, two rows are given; F (for fatal accidents) and A (for all, nonfatal plus fatal). For example, for Group 34 there were 2,188 stall accidents of which 796 were fatal. For the same group the total number of accidents was 41577 of which 5,320 were fatal.

TABLE A1. ACCIDENT SUMMARY FOR GROUPS #32-#36
(1965-1973)
(% SHOWN IS OF TOTAL)

GROUP:	F=FATAL A=ALL	EITHER FIRST OR SECOND ACCIDENT TYPE: STALL		SPIN		SPIRAL		MUSH		TOTAL OF EVERY ACCIDENT TYPE:	
32. GR#1-31	F	500	14%	428	12%	42	1%	59	2%	3639	100%
NO CROP	A	1453	5%	597	2%	111	0%	1306	4%	30606	100%
33. GR#1-31	F	33	31%	22	21%	1	1%	1	1%	106	100%
CROP ONLY	A	72	16%	28	6%	5	1%	49	11%	448	100%
34. ALL SINGLE	F	796	15%	690	13%	64	1%	91	2%	5320	100%
AND TWIN	A	2188	5%	936	2%	161	0%	1932	5%	41577	100%
35. ALL SINGLE	F	678	15%	595	13%	54	1%	69	2%	4449	100%
ENGINE G.A.	A	2003	5%	830	2%	147	0%	1803	5%	36950	100%
36. ALL TWIN	F	118	14%	95	11%	10	1%	22	3%	871	100%
ENGINE G.A.	A	185	4%	106	2%	14	0%	129	3%	4627	100%

The percentages in Table A1 are seen to be rather uniform over all the groups with the exception of Group 33 (crop control only), where stall

accidents account for more than half of the total. It is notable that the percentages for single and twin-engine aircraft are similar. For the nine years of the study there were 3,079 fatalities from stall-related accidents for Group 34 (singles and twins), or an average of 342 deaths per year.

GROUP 32 ACCIDENT RATES

In this and the following three sections the results for Group 32 (all 31 individual single-engine airplanes, but no crop control accidents) are examined.

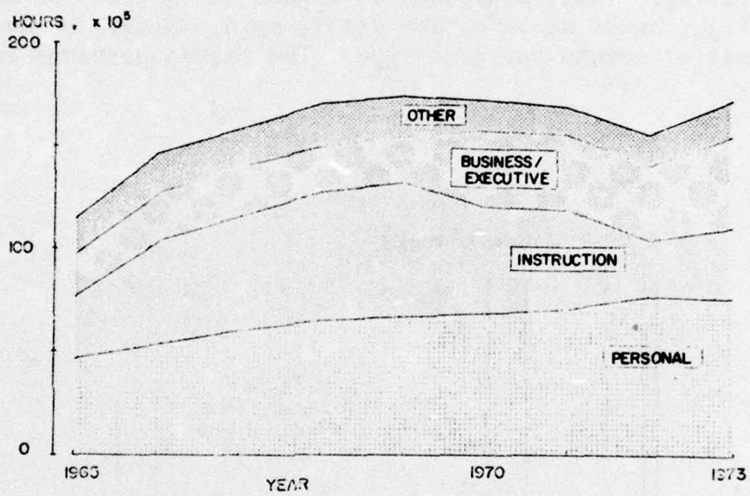


Figure A1. Hours Flown According to Use.

The hours flown by the airplanes in this group are shown in Figure A1 for the nine years of the study. The largest component is seen to be personal use (40.7% of the total hours). Personal use if defined as follows:

> Personal. Any use of an aircraft for personal purposes not associated with a business or profession, and not for hire. This includes maintenance of pilot proficiency.

The next largest component is instructional flying (29.8% of total hours). This is defined as:

> Instruction. Any use of an aircraft for the purpose of formal instruction with flight instructor aboard, or with the maneuvers on the particular flight(s) specified by the flight instructor.

Business/executive, defined below, together account for 18.6% of the total usage.

Business Transportation. Any use of an aircraft not for compensation or hire by an individual for the purpose of transportation required by a business in which he is engaged.

Executive Transportation. Any use of an aircraft by a corporation, company, or other organization for the purposes of transporting its employees and/or property not for compensation or hire and employing professional pilots for the operation of the aircraft.

All other uses (air taxi, "industrial/special," research and development, demonstration, ferry flight, etc.) account for 10.9% of the hours for the group.

The usage figures may be used to form accident rates for the various kinds of flying. These are shown in Figure A2 in terms of accidents per 100,000 flight hours where either stall, spin, spiral, or mush was listed as the first or second accident type. The shaded portions represent fatal accidents.

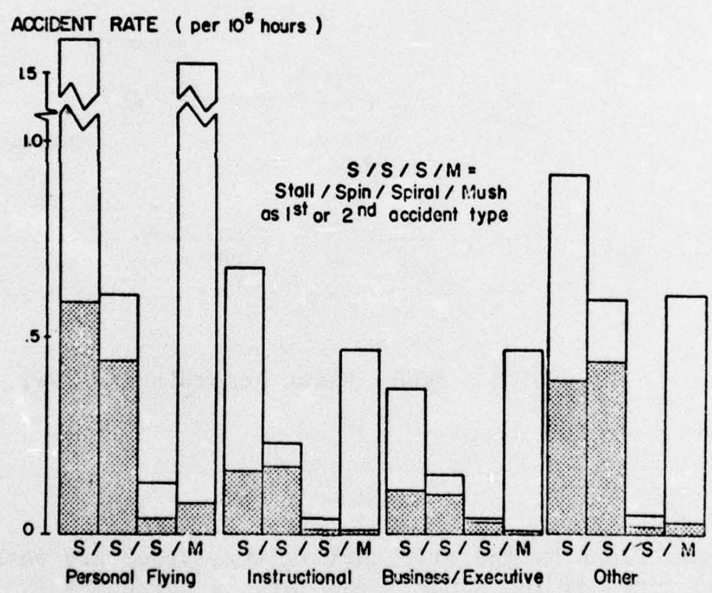


Figure A2. Accident Rate as a Function of Use.

Personal flying clearly has the highest accident rates, with instructional and business flying both significantly better. Within each category stall and spin have the highest rates.

Table A2 gives values for accident rates for all types of usage averaged over the nine years of study. Combined stall, spin, spiral, and mush accidents are seen to give a rate of about 0.7 fatal accidents per 100,000 flight hours; although not shown here, the rates tend to be fairly uniform over the time span.

TABLE A2. FATAL ACCIDENT RATES FOR GROUP 32, 1965-1973
(Either first or second accident types)

Accident Type	Fatal Accidents per 100,000 Hours	Hours per Fatal Accident
STALL	0.348	287,000
SPIN	0.298	336,000
SPIRAL	0.029	3,420,000
MUSH	0.041	2,435,000
STALL + MUSH	0.389	257,000
STALL + SPIN + SPIRAL + MUSH	0.716	140,000
TOTAL OF ALL ACCIDENT TYPES:	2.533	39,500

The inverse of the fatal accident rate is also shown in Table A2. For example, there is an average of 140,000 hours flown between fatal stall, spin, spiral, or mush accidents.

GROUP 32 ACCIDENT DISTRIBUTIONS (STALL OR MUSH LISTED AS FIRST ACCIDENT TYPE)

This section continues the discussion of Group 32 results, but with attention focused on the stall or mush as the first of the two possible accident types (see Appendix B) listed in the accident report. Here comparisons will be made by examining accident distributions rather than rates.

Type of Operator. Accident distributions across types of operators for three categories (stall and mush, spin and spiral, and TOTAL accidents) are compared in Figure A3.

The operator in most cases is a private owner. This is followed by fixed-base operator, flying club, corporate/executive, and flying school. Corporate/executive users have relatively fewer stall and spin accidents than might be predicted on the basis of the group mean.

Kind of Flying. A breakdown of stall and mush accidents by kind of flying is given in Table A3. The percentages shown cumulate down the columns. For example, pleasure flying accounts for 62.6% of all stall accidents for the group (and 68% of fatal stall accidents). This may be compared with the distribution for TOTAL accidents, in which 55.2% occurred in pleasure flying.

For the mush accident, pleasure flying accounts for a percentage of accidents (63.4%) which is similar to that for the stall (62.6%). Instructional flying involves a lower percentage of mush accidents (13.7%) than stall accidents (17.6%) or TOTAL accidents (21.2%).

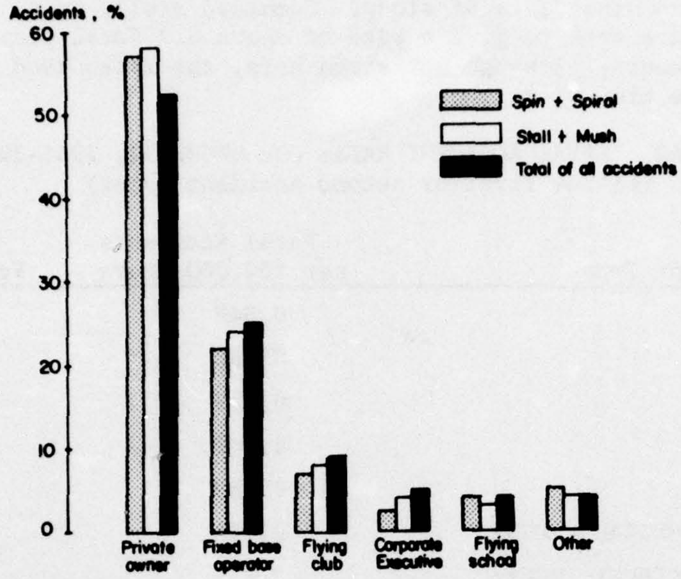


Figure A3. Accident Distributions According to Type of Operator.

TABLE A3. DISTRIBUTION OF ACCIDENTS BY KIND OF FLYING FOR STALL AND MUSH AS THE FIRST ACCIDENT TYPE GROUP #32 (1965-1973) (%s are formed down columns)

	BY FIRST ACCIDENT TYPE:				TOTAL OF EVERY ACCIDENT TYPE:	
	STALL		MUSH			
KIND OF FLYING:	FATAL	ALL	FATAL	ALL	FATAL	ALL
INSTRUCTIONAL	12.4%	17.6%	7.8%	13.7%	9.5%	21.2%
DUAL; CHECK RIDE	5.2%	6.1%	3.9%	6.3%	4.6%	6.5%
SOLO	2.6%	5.6%	2.0%	4.3%	2.0%	8.7%
TRAINING	4.6%	5.9%	2.0%	3.1%	2.9%	6.1%
NONCOMMERCIAL	75.5%	72.4%	84.3%	78.6%	81.3%	72.6%
PLEASURE	68.0%	62.6%	76.4%	63.4%	66.2%	55.2%
PRACTICE	1.8%	2.5%	0	5.4%	1.8%	5.2%
BUSINESS	5.4%	6.7%	5.9%	9.6%	12.8%	11.7%
CORPORATE/EXECUTIVE	0	0.2%	0	0.1%	0.2%	0.2%
OTHER	0.3%	0.4%	2.0%	0.1%	0.3%	0.2%
COMMERCIAL	2.6%	2.8%	2.0%	3.8%	3.5%	2.5%
MISCELLANEOUS FLYING	9.5%	7.2%	3.9%	3.9%	5.7%	3.7%
TOTAL (DOWN COLUMNS):	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
(TOTAL NUMBER)	(388)	(1057)	(51)	(1073)	(3639)	(30606)

Phase of Flight. The distribution of stall, spin, spiral, and mush and TOTAL accidents by phase of flight is shown in Figure A4. The shaded portions represent fatal accidents. For the fatal accidents, the most common flight phase is "in-flight" (which means essentially other than takeoff or landing) except for the mush type of accident which is most often associated with takeoff.

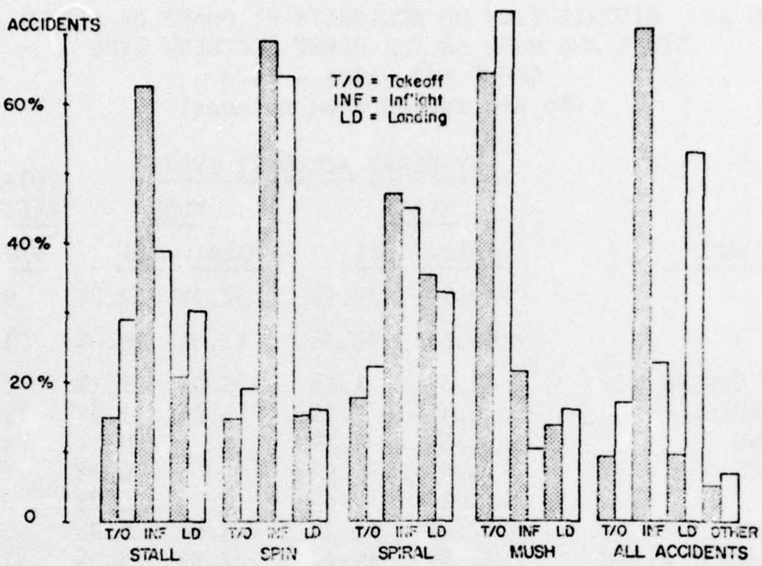


Figure A4. Accident Distribution According to Phase of Flight.

A detailed breakdown is given in Table A4 for stall and mush accidents. Here the major phases are subdivided into several categories. While most (62.6%) of the fatal stall accidents happen in the "in-flight" phase, relatively few (9%) occur in the in-flight operations "climb to cruise," "normal cruise," and "descending." Most of the fatal in-flight stall accidents are associated with "low-pass," "buzzing," "acrobatics," and "other." The "other" category here includes a variety of phases on which NTSB does not give further breakdown, such as uncontrolled descent, hunting, cattle roundup, and unknown - in-flight.

Of the accidents with clearly defined phase it is apparent that low-altitude operations are the most hazardous. For the stall, Table A4 indicates that the in-flight phase accounts for most of the fatal accidents, followed by landing and then takeoff. For the landing phase the largest subcategory is "final approach," but the "go-around" is rather high considering the infrequency of the maneuver compared to the number of operations in the traffic pattern and on final approach.

Takeoff is the flight phase in 28.5% of all stall accidents, but only 14.9% of fatal stall accidents. Takeoff is defined by the NTSB as the period from takeoff run to the point of reduction to climb power.

The takeoff is by far the most important phase for the mush accident. In fact, this phase (and the landing "go-around" which is similar in several respects) almost serve to define the mush accident as opposed to the stall. The distinction between the two is not always clear, although by inference from the data, there are differences in phase distribution and accident severity.

TABLE A4. DISTRIBUTION OF ACCIDENTS BY PHASE OF FLIGHT FOR STALL AND MUSH AS THE FIRST ACCIDENT TYPE
GROUP #32 1965 - 1973
(%s are formed down columns)

	BY FIRST ACCIDENT TYPE:				TOTAL OF EVERY ACCIDENT TYPE:	
	STALL		MUSH			
PHASE OF FLIGHT:	FATAL	ALL	FATAL	ALL	FATAL	ALL
TAKEOFF	14.9%	28.5%	62.7%	72.7%	9.2%	17.0%
INFLIGHT	62.6%	40.3%	21.6%	10.6%	71.1%	22.8%
CLIMB TO CRUISE	2.3%	1.5%	5.9%	1.1%	1.6%	1.0%
NORMAL CRUISE	6.4%	3.7%	3.9%	1.4%	19.3%	11.0%
DESCENDING	0.3%	0.3%	0	0	1.6%	1.4%
ACROBATICS	3.6%	1.6%	0	0.2%	2.9%	0.5%
BUZZING	5.2%	2.6%	0	0.2%	2.7%	0.5%
LOW PASS	12.4%	11.2%	3.9%	3.9%	5.1%	2.1%
OTHER (uncontrolled descent, hunting, cattle roundup, etc.; also unknown-inflight)	32.5%	19.4%	7.8%	3.5%	37.7%	6.4%
LANDING	20.6%	30.2%	13.7%	15.3%	14.5%	53.1%
TRAFFIC PATTERN	5.7%	5.0%	2.0%	0.5%	3.4%	1.7%
FINAL APPROACH	9.0%	12.6%	2.0%	6.2%	6.2%	7.6%
GO-AROUND	5.4%	11.3%	9.8%	8.6%	1.8%	2.3%
OTHER (leveloff, touchdown, roll, etc.)	0.5%	1.3%	0	0.7%	3.2%	41.5%
OTHER (static, taxi, unknown phase)	1.8%	0.7%	0	0	5.2%	7.0%
TOTAL (DOWN COLUMNS):	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
(TOTAL NUMBER)	(388)	(1057)	(51)	(1073)	(3639)	(30606)

The in-flight phase may be seen to account for a disproportionally high percentage (62.6%) of the fatal stall accidents considering that only 40.3% of this type of accident occurs there. The in-flight subcategories suggest that perhaps there is a high incidence of low altitude accelerated stalls in this phase, associated with pull-ups or turning maneuvers.

The question of whether the airplane was turning or not just prior to the stall cannot be answered by reference to the NTSB coded tapes. It is an important consideration, however, and the information can in some cases be determined from the original accident reports. Examination of the files of 48 fatal stall accidents for 1973 yielded the results shown in Table A5.

TABLE A5. BREAKDOWN OF FATAL STALL ACCIDENTS BY TURNING AND CLIMBING MANEUVERS
(based on a Survey of 48 Accidents from 1973)

Phase and Maneuver	Number of Accidents	
In-Flight		
Turning	13	
Climbing	6	
Turning and Climbing	2	
Not Turning or Climbing	2	
Unknown	6	
Subtotal		29
Takeoff or Landing		
Initial Climb (Turn)	6	
Initial Climb (No Turn)	3	
Departing Pattern (Turn)	2	
Departing Pattern (Climb)	1	
Turn, Downwind to Base	1	
Base Leg (No Turn)	1	
Turn, Base to Final	2	
Final Approach (In Turn)	1	
Unknown	2	
Subtotal		19

Thus the table indicates that the 40 accidents in which the prestall maneuver is known, 24 (or 60%) involved turning and 34 (or 85%) involved turning and/or climbing.

Conditions of Light. The record indicates that most general aviation accidents occur in daylight, corresponding to the fact that most flying takes place in daylight. Table A6 presents the distribution of stall, mush and TOTAL (of all accident types) by condition of light. This shows that the stall accident is even more a daylight phenomenon than other types. Note the relatively high percentage of fatal night accidents in the TOTAL column.

TABLE A6. DISTRIBUTION OF ACCIDENTS BY CONDITION OF LIGHT FOR STALL AND MUSH AS THE FIRST ACCIDENT TYPE
GROUP #32 1965 - 1973
(%s are formed down columns)

	BY FIRST ACCIDENT TYPE:				TOTAL OF EVERY ACCIDENT TYPE:	
	STALL		MUSH			
CONDITION OF LIGHT:	FATAL	ALL	FATAL	ALL	FATAL	ALL
DAYLIGHT	91%	93%	92%	93%	69%	86%
DAWN OR DUSK	3%	3%	6%	3%	5%	4%
NIGHT	6%	5%	2%	3%	26%	10%

Weather Conditions. Not only do more than 90% of stall accidents occur in daylight, but they also happen essentially in fair weather. This information is presented in Table A7 for stall, mush, and TOTAL accidents. For the accidents reported as stalls, 96% were in VFR conditions; for mush accidents the incidence is 99%. Also noteworthy is the relatively high incidence of IFR weather accidents in the TOTAL column.

Almost 90% of the accidents happended with no flight plan filed; the remainder were under a VFR flight plan.

TABLE A7. DISTRIBUTION OF ACCIDENTS BY WEATHER CONDITION FOR STALL AND MUSH AS THE FIRST ACCIDENT TYPE
GROUP # 32 1965 - 1973
(%s are formed down columns)

	BY FIRST ACCIDENT TYPE:				TOTAL OF EVERY ACCIDENT TYPE:	
	STALL		MUSH			
WEATHER:	FATAL	ALL	FATAL	ALL	FATAL	ALL
VISUAL FLIGHT RULES (VFR)	93%	96%	98%	99%	73%	95%
INSTRUMENT FLT. RULES (IFR)	7%	4%	2%	1%	27%	5%

Airport Proximity. The proximity of the nearest airport to the accident site is coded on the NTSB tapes. For stall accidents, the occurrence tends to be either within the traffic pattern or at a distance greater than 5 miles. The mush accident happens predominantly near airports, which correlates with the earlier-cited association with the takeoff phase. For both stall and mush accidents, those which occur away from an airport tend to be more severe.

Airport Characteristics. The distribution of all accidents happening at airports indicates that most of those for Group 32 occur at "local" airports, followed by "municipal" and "private" fields. However, for stall and mush accidents there is a relatively larger frequency at "private" airports and a relatively smaller frequency at those termed "municipal."

Mush accidents are more frequently associated with unpaved than paved runways, the reverse of the situation found for TOTAL accidents. The stall accident falls in between, with roughly equal numbers for paved and unpaved runways.

The distribution relative to runway length shows that the mush is relatively more likely at short fields (1500 to 2500 ft), although the stall distribution is very nearly the same as that for TOTAL accidents (most accidents occurring where runway length is between 1500 and 5000 ft - which probably encompasses the largest percentage of general aviation airports).

The percentage of stall and mush accidents at high altitude (greater than 2500 ft elevation) fields is somewhat greater than the percentage of TOTAL accidents.

Pilot Experience. The following five items related to pilot experience are covered in this section; each is recorded by the NTSB for almost every accident:

Total time
Time in type
Age
Instrument Rating (yes or No)
Pilot Certificate held (student, private, etc.)

The distribution of accidents as a function of total time is shown in Figure A5 (note that the absicissa is nonlinear). In considering this plot the matter of exposure must be considered. It would be very desirable to compare this accident distribution with a distribution of pilot experience for all aircraft in the group, but this is not available. The next best thing is to compare the stall and mush accident distributions with that for some other type of accident, preferably one which is a random event, unrelated to pilot experience. The one picked here is "true engine failure." defined as an actual powerplant breakdown not due to piloting

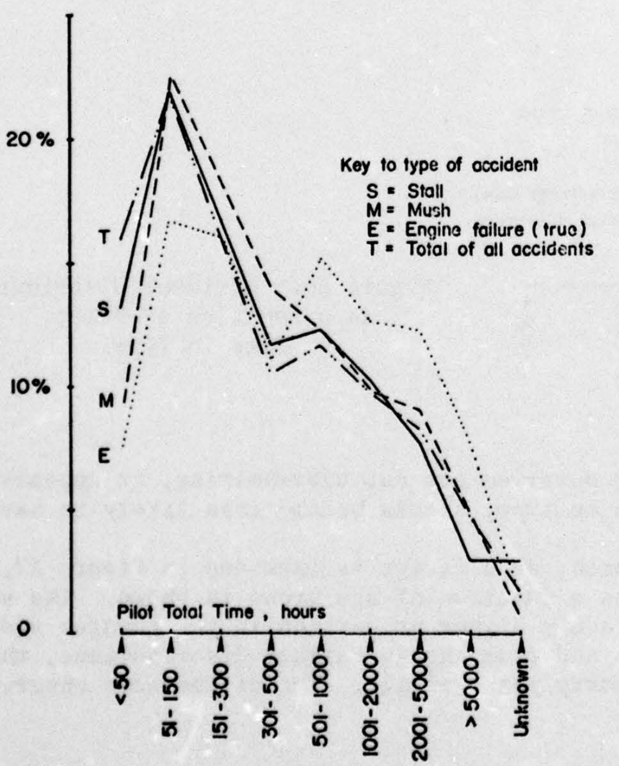


Figure A5. Accident Distribution as a Function of Pilot Total Flight Time.

factors such as fuel mismanagement (although it might be argued that higher time pilots might be better able to detect an impending failure and take precautionary measures to avoid an accident).

If the true engine failure accidents are accepted as a somewhat random event, Figure A5 indicates that stall, mush, and TOTAL accidents occur more frequently to low time pilots less frequently to high time individuals, thus bearing out one's intuition that experience decreases the likelihood of an accident. The crossover point on total time appears to be about 500 hours; stall and mush accidents are relatively more likely below that figure, and less likely above.

Figure A6 presents a similar picture for time in type. Again, stall, mush, and TOTAL accident distributions are above that for true engine failure for low time pilots and vice versa; the curves cross over in the neighborhood of 100 hours in type.

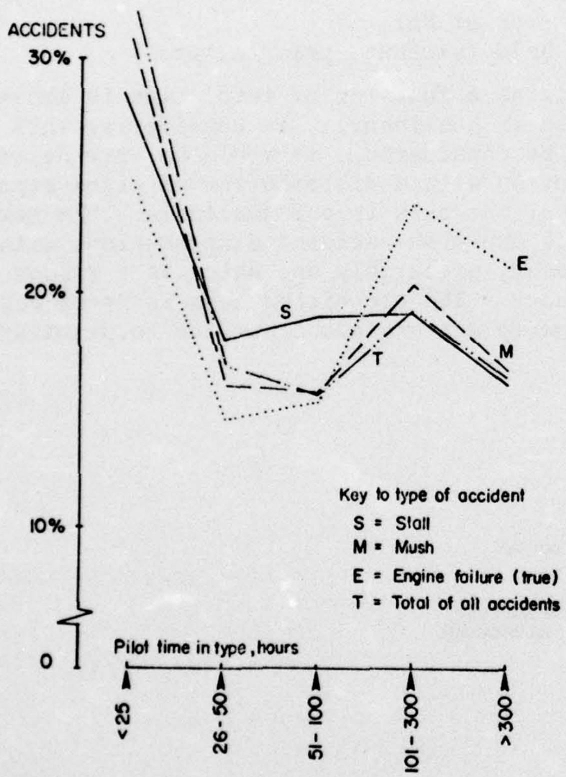


Figure A6. Accident Distribution as a Function of Pilot Time in Type.

Although the differences observed are not overwhelming, it appears that after 500 hours and 100 hours in type, pilots become less likely to have a stall or mush accident.

Age, rather than experience, as a factor is examined in Figure A7, where accident distribution as a function of age group is shown. The stall and mush accidents show a markedly higher proportion in the younger age groups relative to both TOTAL and true engine failure distributions, the crossover point being about forty years of age. The differences observed

according to pilot age are more striking than those seen above for experience, a possible implication being that the element of caution enters the picture in a significant way.

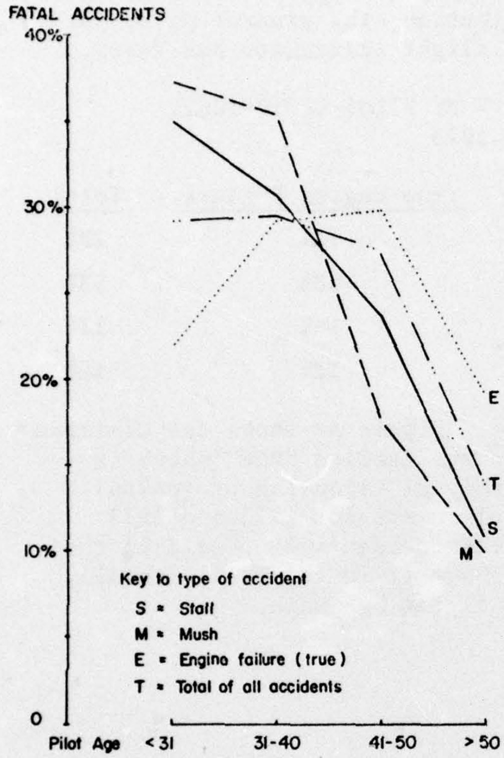


Figure A7. Accident Distribution as a Function of Pilot Age.

Although stall and mush accidents have been shown to be overwhelmingly fair-weather, daytime occurrences, the instrument rating should be indicative of a higher level of pilot proficiency. Table A8 shows that the distribution of stall, mush and TOTAL accidents is nearly the same relative to instrument rating, but the true engine failure is notably different. If the true engine failure is accepted as a nearly random event, then it appears that the instrument rated pilots are more successful in avoiding accidents.

TABLE A8. DISTRIBUTION OF ACCIDENTS BY PILOT INSTRUMENT RATING GROUP 32 1965-1973

Instrument Rating	Stall	Mush	True Engine Failure	Total of Every Accident Type
YES:	16%	15%	24%	16%
NO:	84%	85%	76%	84%

The final pilot factor to be considered here is the category of pilot certificate - student, private, commercial (or ATR without flight instructor rating) or flight instructor (including ATR with flight instructor rating). Table A9 summarizes the results, with percentages to be added down the columns. Slightly more than half of the accidents happen to private pilots. Compared to the true engine failure distribution, the student pilot has relatively more stall accidents while the flight instructor has fewer.

TABLE A9. DISTRIBUTION OF ACCIDENTS BY PILOT CERTIFICATE
GROUP 32 1965-1973

Certificate:	Stall	Mush	True Engine Failure	Total
Student	20%	14%	12%	22%
Private	54%	57%	53%	53%
Commercial	13%	15%	16%	13%
Flight Instructor	13%	13%	18%	12%

Month of the Year and Air Temperature. Figure A8 shows the distribution of accidents by month, along with a curve labeled "REF" which is based on a numerical smoothing of the monthly distribution of general aviation operations reported by FAA control towers for 1973 and 1974 (Reference A3). This curve tracks the TOTAL accidents line well in the spring but is below it in the summer and above it in the fall; overall, it appears to be a reasonable estimate of flying by month.

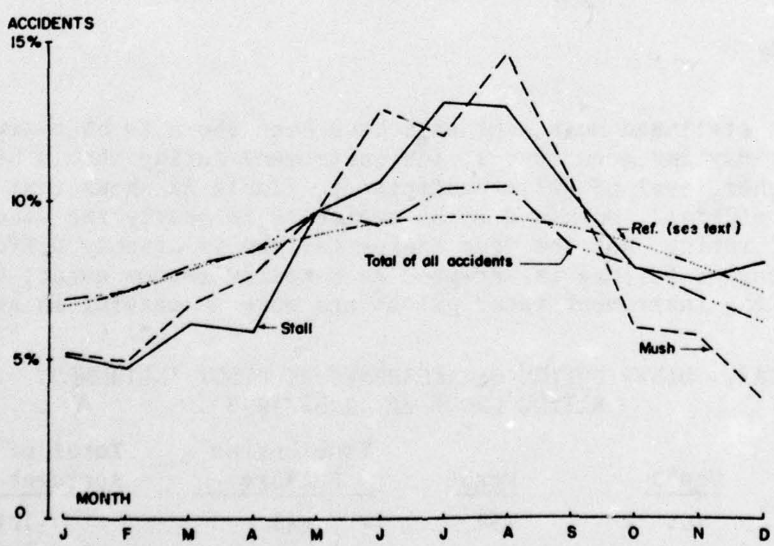


Figure A8. Accident Distribution by Month of Year

Relative to both REF and TOTAL, the stall and mush traces show a definite seasonal variation, being higher in summer and lower in winter, a finding probably related to the following factor temperature.

The distribution relative to temperature is given in Figure A9, when compared to TOTAL accidents, stall and mush are more frequent at high temperatures and less frequent at low ones.

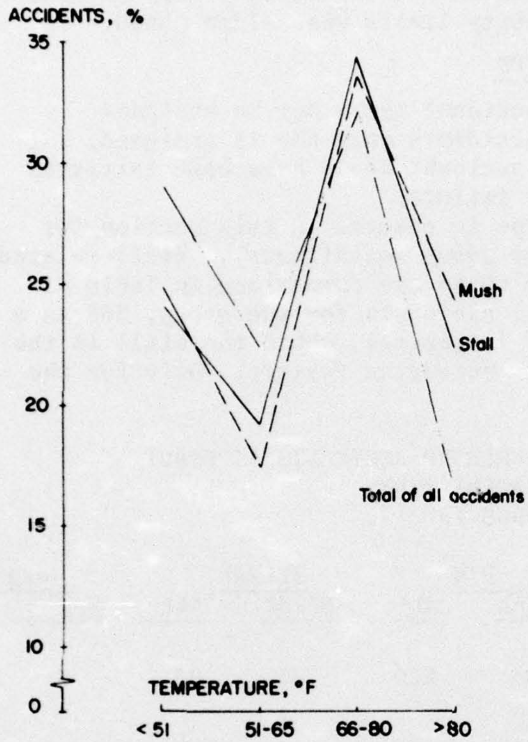


Figure A9. Accident Distribution According to Temperature.

Stall Warning Indicator. A stall warning indicator is required by FAR Part 23, § 23,207 for modern production airplanes which do not demonstrate clear and distinctive natural warning, such as aerodynamic buffeting. However, some older designs do have such a device.

The NTSB does not record whether a stall warning indicator was installed for every accident; the information is probably recorded more often in the now-unusual case of such a device not being present. Table A10 summarizes the available data for Group 32 by accident type.

TABLE A10. STALL WARNING INDICATOR INSTALLED?

ACCIDENT TYPE: (first type)	YES:	NO:
STALL	68%	32%
SPIN	50%	50%
SPIRAL	79%	21%
MUSH	82%	18%
TRUE ENGINE FAILURE	84%	16%
TOTAL OF EVERY ACCIDENT TYPE:	81%	19%

According to the table, one-third of the stall accidents and one-half of the spin accidents involved airplanes without stall warning indicators (88 stall and 115 spin accidents are represented).

Weight and Balance. The NTSB data on weight and balance for airplanes involved in accidents is very sparse, it not being a required entry in the coding system. The most prevalent indication - still sparse - is that a mush type accident is more likely with an overloaded airplane, an expected finding. A violation of center of gravity limits was seldom noted.

GROUP 32 RESULTS BY SECOND ACCIDENT TYPE

As discussed in Appendix B, two accident types may be assigned (sequentially) by the NTSB. In most accidents only one is assigned, but it is easily appreciated that a stall accident could have been initiated by an earlier event, such as an engine failure.

The stall as a second accident type is covered in this section for Group 32 (see page A2 or Appendix C for group definitions). Stall-related accidents as first and second accident types are summarized in Table A11. For example, there were 500 fatal stall accidents for the group, 388 as a first accident type, 112 as a second. In general, where the stall is the second accident type, the first type is an engine failure. Only for the mush accident is this not so.

TABLE A11. SUMMARY OF STALL RELATED ACCIDENTS AS FIRST AND SECOND ACCIDENT TYPES
GROUP 32 1965-1973

	STALL		SPIN		SPIRAL		MUSH	
	FATAL	ALL	FATAL	ALL	FATAL	ALL	FATAL	ALL
AS FIRST ACCIDENT TYPE:	388	1057	381	529	34	91	51	1073
AS SECOND ACCIDENT TYPE:	112	396	47	68	8	20	8	233
EITHER FIRST OR SECOND:	500	1453	428	597	42	111	59	1306
SECOND ACCIDENT TYPE PRECEDED BY ENGINE FAILURE AS FIRST TYPE:	88%	74%	81%	79%	75%	80%	50%	40%

When engine failure is cited as the first accident type, the most li ly flight phases to be involved are takeoff and in-flight (about 40% each), both for stall and mush second accident type; the landing phase is less common (about 20%). Non-engine-failures, as first-types, are more likely (85%) to be initiated in the landing phase in the form of overshoots, undershoots, hard landings or ground loops; the subsequent stall or mush then occurs in a go-around or on final approach.

Table A12 presents a comparison of stall and mush as first and second accident types according to the kind of flying. Note that the percentage of accidents which occurs in instructional flying is higher for stall and mush as second accident types than as first types. For those stall or mush

accidents preceded by an engine failure, 63% were "complete" failures, 28% were "partial" power losses, and 9% were "simulated" engine failures.

TABLE A12. DISTRIBUTION OF ACCIDENTS BY KIND OF FLYING
FOR FIRST AND SECOND ACCIDENT TYPES
GROUP 32 1965-1973

(Percentages formed down columns)

	STALL		MUSH	
KIND OF FLYING	FIRST TYPE	SECOND TYPE	FIRST TYPE	SECOND TYPE
INSTRUCTIONAL	17.6%	26.8%	13.7%	24.0%
PERSONAL	65.1%	58.3%	68.8%	61.8%
EXECUTIVE-BUSINESS	6.9%	6.6%	9.7%	9.4%
OTHER	10.4%	8.3%	7.8%	4.7%
ALL KINDS OF FLYING:	100.0%	100.0%	100.0%	100.0%

GROUP 32 RESULTS - CAUSES AND FACTORS

While the type of accident is intended to tell what happened, the cause is intended to indicate why it happened. The NTSB has the responsibility for determining this "probable cause," and has established some 860 codes which may be used for the purpose. Often more than one cause is assigned to a single accident; when this is done, all are considered to have equal weight.

The same codes are available for selection as "factors," which are not considered to have as much causal significance as the "causes." The formal definitions of the two terms are:

- CAUSE: Had the condition or event been prevented, the accident would not have occurred.
- FACTOR: A related condition or event, the omission of which would not necessarily have prevented the accident.

Table A13 presents the ten most frequently cited pilot in command cause factors, ordered according to a formula which counts fatal accidents ten times heavier than non-fatal ones, and "causes" twice as heavy as "factors."

The most common cause cited for stall accidents is the following: "Pilot in command failed to obtain or maintain flying speed." It must be taken on faith that the NTSB means by this statement that the stall angle of attack was reached or exceeded, and control over the flight path was adversely affected. (A severe deceleration from an already-low speed would cause a downward change in flight path, but it is hard to imagine this happening unless very effective flaps, spoilers, dive brakes, thrust reversers, or Beta propellers were deployed, or severe wind shear encountered; and none of these would necessarily produce the high angle of attack flow separation which ordinarily defines a stall.) At any rate, the citation clearly indicates that the pilot is at fault, and this cause is listed in 91% of stall accidents and 76% of mush accidents for the Group 32 airplanes.

TABLE A13. PERCENT OF ACCIDENTS IN WHICH PILOT IN COMMAND IS CITED AS A CAUSE/FACTOR
GROUP #32 1965 - 1973

	FIRST ACCIDENT TYPE:			
	STALL		MUSH	
CAUSE/FACTOR DESCRIPTION:	CAUSE	FACTOR	CAUSE	FACTOR
ALL PILOT IN COMMAND:	98.8%	14.3%	98.5%	11.5%
Failed to obtain or maintain flying speed:	91.0%	0	76.0%	0
Inadequate preflight preparation and/or planning:	6.5%	2.6%	14.6%	2.3%
Exercised poor judgement:	4.0%	0.5%	2.8%	0
Improper inflight decisions or planning:	3.2%	0.7%	1.7%	0.1%
Premature liftoff:	3.9%	0	24.2%	0.3%
Diverted attention from operation of aircraft:	5.0%	2.7%	1.3%	0.4%
Physical impairment (includes drinking)	2.6%	0.8%	0.2%	0
Continued VFR flight into adverse weather conditions:	2.9%	0.2%	0.5%	0
Improper operation of flight controls:	3.8%	0	2.0%	0.1%
Misused or failed to use flaps:	2.1%	2.6%	4.9%	3.0%

It is noteworthy that over 20% of the mush accidents are associated with premature liftoff.

Causes and factors not assigned to the pilot in command are shown in Table A14, ordered according to the same rules used in constructing the previous table. The first block summarizes weather cause/factors. In a previous section it was pointed out that stall and mush accidents are typically fair weather events, and in fact Table A14 indicates that weather is a cause in less than 5% of the cases and a factor in less than 25%. Most often cited is high density altitude, which is listed under weather in the NTSB coding system: low ceiling, icing, and fog are cited in fewer than 3% of the accidents.

The second block of Table A14 lists miscellaneous factors, some of them clearly associated with some other citation directed to the pilot in command (such as "exercised poor judgment"). The list is headed by "unwarranted low flying," which is consistent with the "buzzing" and "low pass" items discussed earlier in connection with accident distributions. High obstructions are considered a cause or factor in about 5% of the cases; this is coded only when obstruction is considered to be of more than normal height, and the airplane stalled or mushed during an attempt to avoid the obstacle.

The cause/factor labeled "airframe came to rest in water" implies that the machine ended up in the water after the accident and that this was significant to the damage or injuries sustained.

RESULTS FOR INDIVIDUAL AIRCRAFT

Background. In this section the stall-related accident rates for the 31 individual aircraft compromising Group 32 are presented and discussed. Appendix C gives a full description of the makes and models included; for brevity, the "short names" of Appendix C will be used to refer to individual aircraft (for example, "ERCOUPE" will mean Group 2: Ercoupe 415, Forney F-1, Alon A2, and Mooney M10).

The objective here is to determine how the accident patterns for individual makes and models compare with the patterns for the 31 aircraft as a group. Statistical tests are applied to determine whether the observed differences and the sample size are sufficiently large to justify a statement that the pattern is significant. The statistical test most often used is the "Chi-square" test. This permits one to state that the observed differences in accidents (rates or percentages) could have occurred by chance with a probability which is lower than a selected value. Two measures are used here, one based on a probability of 5% or less, and another more stringent test based on 0.1%. The tested accident patterns are "flagged" as follows:

Flag	Accident Rate Compared to Group	Probability of Chance Result
H	HIGH	5% or less
L	LOW	
VH	VERY HIGH	0.1% or less
VL	VERY LOW	

TABLE A14. CAUSE/FACTOR (OTHER THAN PILOT IN COMMAND) CITATIONS
GROUP #32 1965 - 1973

	FIRST ACCIDENT TYPE			
	STALL		MUSH	
CAUSE/FACTOR DESCRIPTION:	CAUSE	FACTOR	CAUSE	FACTOR
WEATHER:	2.8%	19.2%	4.1%	24.3%
High density altitude:	0.2%	7.5%	1.6%	12.4%
Downdrafts, updrafts:	0.7%	2.9%	0.7%	4.4%
Unfavorable wind conditions:	1.0%	4.1%	1.3%	4.7%
Low ceiling:	0	2.9%	0.1%	0.3%
Icing conditions:	0.8%	1.0%	0.2%	0.5%
Fog:	0.1%	2.1%	0.1%	0.4%
MISCELLANEOUS CAUSE/FACTORS:				
Unwarranted low flying:	7.9%	6.1%	0.7%	0.5%
Alcoholic impairment of efficiency and judgment:	2.6%	0.4%	0.2%	0
Improperly loaded aircraft (weight and balance):	0.9%	2.2%	2.3%	2.9%
Flew into a blind canyon:	1.9%	1.3%	0.7%	0.3%
High obstructions (towers, hills, trees, etc.)	0.5%	5.1%	1.3%	5.6%
Airframe came to rest in water:	0	5.7%	0	2.7%
Airframe ice:	1.5%	0.9%	2.5%	1.0%
Poorly planned approach:	0.5%	2.8%	0.1%	0.4%
Evasive maneuver (such as collision avoidance)	2.4%	1.3%	0.9%	0.5%

Accident Statistics for 31 Aircraft. Accident count and rate data for the 31 individual aircraft groups are presented in Table A15, with crop control hours and accidents excluded. The accident rates shown are per 100,000 flight hours. A comparison is made relative to the 31 aircraft

TABLE A15. TOTAL ACCIDENT STATISTICS FOR 31 SINGLE-ENGINE AIRCRAFT (1965 - 1973)

GR. #	SHORT NAME:	TOTAL ACCIDENTS FATAL	TOTAL ACCIDENTS ALL	HOURS X 10^5	TOTAL ACCID. RATE FATAL	TOTAL ACCID. RATE ALL	RELATIVE TO GR.#32; CHI-SQUARE FATAL		RELATIVE TO GR.#32; CHI-SQUARE ALL	
1	AERON.11	18	162	3.595	5.01	45.06	+98%	H	+112%	VH
2	ERCOUPE	49	505	13.727	3.57	36.79	+41%	H	+73%	VH
3	YANKEE	35	194	6.060	5.78	32.02	+128%	VH	+50%	VH
4	B-23	63	789	25.505	2.47	30.94	-2%		+45%	VH
5	BONANZA	342	1840	105.359	3.25	17.46	+28%	VH	-18%	VL
6	BELLANCA	27	216	6.517	4.14	33.14	+64%	H	+56%	VH
7	CITABRIA	162	1293	35.386	4.58	36.54	+81%	VH	+72%	VH
8	C-140	61	991	24.944	2.45	39.73	-3%		+87%	VH
9	C-150	387	4290	284.885	1.36	15.06	-46%	VL	-29%	VL
10	C-170	64	712	21.541	2.97	33.05	+17%		+55%	VH
11	C-172	343	2723	192.896	1.78	14.12	-30%	VL	-34%	VL
12	C-175	36	261	12.884	2.79	20.26	+10%		-5%	
13	C-180	68	853	31.933	2.13	26.71	-16%		+25%	VH
14	C-182	214	1872	104.616	2.05	17.89	-19%	L	-16%	VL
15	C-185	20	196	9.359	2.14	20.94	-15%		-2%	
16	C-206	33	319	21.948	1.50	14.53	-41%	L	-32%	VL
17	C-210	102	755	32.960	3.09	22.91	+22%	H	+8%	H
18	C-177	48	478	14.852	3.23	32.18	+28%		+51%	VH
19	MOONEY	193	1185	56.566	3.41	20.95	+35%	VH	-2%	
20	NAVION	63	304	10.094	6.24	30.12	+147%	VH	+41%	VH
21	CUB	96	635	19.051	5.04	33.33	+99%	VH	+56%	VH
22	PA-12	21	296	9.171	2.29	32.28	-9%		+52%	VH
23	PA-18	119	751	26.694	4.46	28.13	+76%	VH	+32%	VH
24	TRIPACER	160	1687	55.552	2.88	30.37	+12%		+43%	VH
25	COMANCHE	200	1398	49.117	4.07	28.46	+61%	VH	+34%	VH
26	CHEROKEE	459	3674	204.634	2.24	17.95	-11%	L	-16%	VL
27	CHER-6	65	401	23.886	2.72	16.79	+8%		-21%	VL
28	LUSCOMBE	59	731	11.088	5.32	65.93	+110%	VH	+210%	VH
29	TAYLORCR	51	339	8.404	6.07	40.34	+140%	VH	+89%	VH
30	SWIFT	33	255	3.280	10.06	77.74	+298%	VH	+265%	VH
31	STINSON	48	501	10.069	4.77	49.76	+89%	VH	+134%	VH
32	GR.#32	3639	30606	1436.573	2.53	21.30	0		0	

taken as a group (Group 32, at the bottom of the table); this is shown as a percentage difference between the rate for a given aircraft make and that for Group 32. For example, the first airplane listed, "AERON 11," has a fatal accident rate of 5.01 and this is larger than that for Group 32 by 98%. The Chi-square test is applied to the difference, and in this example is found to satisfy the 5% test; hence the "H" flag is appended to the 98%

shown in the second column from the right. To continue the example, the count of ALL (fatal plus non-fatal) accidents for the AERON. 11 is 162. The resulting rate is 45.06, more than double that of the comparison group, and explained by chance with a probability of 0.1% or less (VH flag).

In reviewing these results it is noteworthy that there are large observed differences in accident rates, and a high incidence of Chi-square test flags. The latter reflects the very large data base. There are more VERY HIGH flags than VERY LOW flags, which arises from the fact that several very popular airplanes have lower than average accident rates. The lowest fatal accident rate is attained by the Cessna 150, which also flew more hours than any other airplane in the nine years of the study.

In Table A16, stall-related accidents for the 31 aircraft have been

TABLE A16. STALL, SPIN, SPIRAL, MUSH ACCIDENTS FOR 31 SINGLE-ENGINE AIRCRAFT (1965-1973) ACCIDENT COUNT (EITHER FIRST OR SECOND ACCIDENT TYPE):

GR.	SHORT	STALL		SPIN		SPIRAL		MUSH	
#	NAME	FATAL	ALL	FATAL	ALL	FATAL	ALL	FATAL	ALL
1	AERON.11	6	20	10	18	0	1	0	9
2	ERCOUPE	6	24	0	1	2	3	0	19
3	YANKEE	11	23	14	18	0	0	0	13
4	B-23	14	33	4	5	0	0	1	50
5	BONANZA	39	64	33	36	7	9	3	71
6	BELLANCA	2	5	0	1	0	0	0	3
7	CITABRIA	40	131	61	85	0	6	4	65
8	C-140	13	45	14	21	1	4	0	41
9	C-150	73	263	83	101	7	20	2	164
10	C-170	9	35	12	15	3	3	0	45
11	C-172	37	120	10	16	2	4	7	120
12	C-175	1	8	5	5	0	0	0	16
13	C-180	5	21	1	2	1	2	1	26
14	C-182	13	31	5	10	1	2	0	32
15	C-185	2	4	0	0	0	0	0	5
16	C-206	5	5	1	2	0	0	1	10
17	C-210	4	7	4	5	1	2	1	7
18	C-177	8	35	4	4	0	1	6	53
19	MOONEY	26	46	15	17	4	4	4	45
20	NAVION	6	13	2	2	0	1	2	14
21	CUB	28	101	38	57	0	2	1	57
22	PA-12	2	16	4	6	0	2	0	15
23	PA-18	38	92	25	36	1	8	2	46
24	TRIPACER	19	43	8	15	2	6	3	54
25	COMANCHE	11	19	14	15	1	2	4	47
26	CHEROKEE	39	111	12	19	8	13	13	159
27	CHER-6	5	9	4	4	0	0	1	16
28	LUSCOMBE	16	44	15	30	1	11	0	28
29	TAYORCR	9	35	26	43	0	3	1	29
30	SWIFT	8	21	3	4	0	1	2	29
31	STINSON	5	29	1	4	0	1	0	18
32	GR.#32	500	1453	428	597	42	111	59	1306

extracted from the overall accident count. The AERON. 11, for example, had 20 stall accidents, 6 of them fatal. This may be compared with the total of 18 fatal accidents listed in Table A15. The airplane also had 10 fatal spin accidents, and thus 16 out of a total of 18 fatal accidents were due to stall or spin.

For purposes of comparison, two different measures were formed from the data in the tables above. One involved computing accident rates; the other percentages of TOTAL accidents accounted for by a particular accident type. (Rate data alone could be misleading if the airplane has an unusual usage pattern; percentage data alone might also mislead if, for example, an airplane had few accidents but they were all of one type.) Using the AERON. 11 as an example again, the tables show a total of 29 stall and mush accidents (as either first or second type) for a rate of 8.07; this may be compared with a similarly-obtained rate of 1.92 for comparison Group 32. Considering the second approach, the percentage of total AERON. 11 accidents (162) accounted for by stall or mush accidents (29) is 17.9%.

Using the two approaches above, measures for stall and mush accidents were formed for the 31 airplanes which were then ranked accordingly, as shown in Table A17. Two rankings are given, both of which weigh fatal accidents more heavily than non-fatal ones. RANK 1 is based on accident rates, according to the sum 10 x (Fatal Stall and Mush Accident Rate) + (Stall and Mush Accident Rate); RANK 2 is based on the percentage of TOTAL accidents represented by stall and mush, according to 10 x (Fatal Stall and Mush as a Percentage of TOTAL accidents) + (All Stall and Mush Accidents as a Percentage of TOTAL Accidents). In both cases the individual rates and percentages are compared with Group 32 and tested with a Chi-square technique.

The airplane with the best stall/mush safety record, according to RANK 1 is the Cessna 182, and its accident rates are Chi-square VERY LOW with respect to the comparison group. The 182 is ranked number 3 according to the other system, which finds the Cessna 175 on top; however, this airplane had insufficient exposure to activate the Chi-square flags.

The two ranking systems in Table A17 show a rather high degree of correlation, the top three and bottom nine (with one exception, the Taylorcraft) airplanes being the same in each case, although in different order. Most of the airplanes near the bottom are older designs, dating in some cases back to the 1940's and before; exceptions are the Beech 23, Cessna 177, and Grumman American Yankee, all of them of relatively recent design.

Figure A10 is a graphical presentation of the accident data, showing fatal stall and mush accidents as a percentage of TOTAL accidents versus the fatal accident rate for each aircraft. The results for the summary group (Group 32) are shown by dashed lines; thus an airplane plotted in the upper right-hand quadrant has both a total fatal accident rate and a percentage of fatal stall/mush accidents higher than the group mean.

A third approach may be taken which considers the sample size in addition to the accident rate in ranking the aircraft. In this case, the Chi-square test itself is used, and the more populous airplanes will tend to migrate to the top or bottom of the list because their results have the benefit of a larger data sample.

TABLE A17. TWO STALL/MUSH RANKING SYSTEMS FOR 31 SINGLE-ENGINE AIRCRAFT (1965 - 1973)

RANK 1: Ranked according to (10 x FATAL Rate + ALL Rate)

RANK 2: RUanked according to (10 x FATAL % + ALL %)

			EITHER STALL OR MUSH AS FIRST OR SECOND ACCIDENT TYPES:								
			ACCIDENT RATES:				% OF TOTAL:				
RANK1	GR. #	SHORT NAME	FATAL		ALL		FATAL		ALL		RANK2
1	14	C-182	0.12	VL	0.60	VL	6.1%	VL	3.4%	VL	3
2	17	C-210	0.15	VL	0.43	VL	4.9%	L	1.9%	VL	2
3	12	C-175	0.08	VL	1.86	VL	2.8%		9.2%		1
4	15	C-185	0.21	L	0.96	VL	10.0%		4.6%		8
5	13	C-180	0.19	L	1.47	VL	8.8%		5.5%		6
6	16	C-206	0.27		0.68		18.2%		4.7%	L	19
7	11	C-172	0.23		1.24		12.8%		8.8%		15
8	27	CHER-6	0.25		1.05		9.2%		6.2%		7
9	26	CHEROKEE	0.25		1.32		11.3%	L	7.3%	VL	11
10	9	C-150	0.26		1.50		19.4%		10.0%	H	20
11	6	BELLANCA	0.31		1.23	VL	7.4%		3.7%	L	4
12	25	COMANCHE	0.31		1.34	L	7.5%	L	4.7%	VL	5
13	5	BONANZA	0.40		1.28	H	12.3%		7.3%	L	12
14	22	PA-12	0.22		3.38		9.5%		10.5%		9
15	24	TRIPACER	0.40		1.75		13.8%		5.7%	VL	16
16	19	MOONEY	0.53		1.61	VL	15.5%		7.7%		18
17	2	ERCOUPE	0.44		3.13	VH	12.2%		8.5%		13
18	10	C-170	0.42		3.71	H	14.1%		11.2%	H	17
19	8	C-140	0.52		3.45	VH	21.3%		8.7%		22
20	4	B-23	0.59		3.25	VH	23.8%		10.5%		23
21	31	STINSON	0.50		4.67	VH	10.4%		9.4%		10
22	20	NAVION	0.79	H	2.68		12.7%		8.9%		14
23	18	C-177	0.94	VH	5.93	VH	29.2%	H	18.4%	VH	26
24	7	CITABRIA	1.24	VH	5.54	VH	27.2%	VH	15.2%	VH	25
25	29	TAYLORCR	1.19	VH	7.62	VH	19.6%		18.9%	VH	21
26	23	PA-18	1.50	VH	5.17	VH	33.6%	VH	18.4%	VH	31
27	28	LUSCOBME	1.44	VH	6.49	VH	27.1%	H	9.8%		24
28	21	CUB	1.52	VH	8.29	VH	30.2%	VH	24.9%	VH	28
29	3	YANKEE	1.82	VH	5.94	VH	31.4%	H	18.6%	VH	29
30	1	AERON.11	1.67	VH	8.07	VH	33.3%	H	17.9%	VH	30
31	30	SWIFT	3.05	VH	15.24	VH	30.3%	H	19.6%	VH	27
	32	GR.#32	0.389		1.92		15.36%		9.02%		

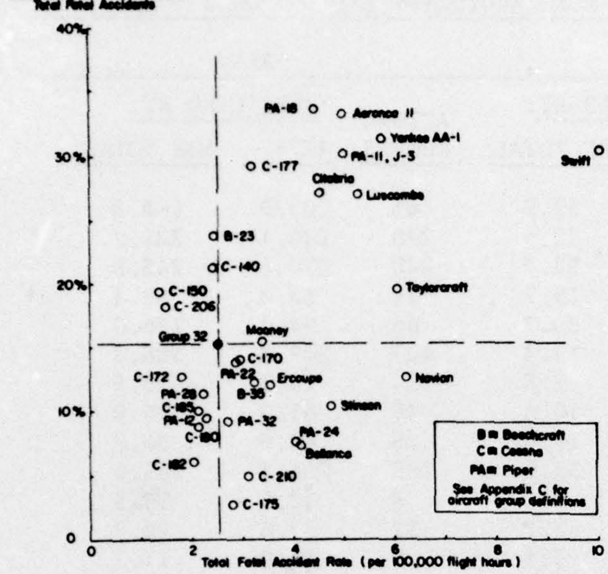


Figure A10. Fatal Stall and Mush Accident Percentage versus Total Fatal Accident Rate for Group 32 Airplanes.

A ranking based on the Chi-square test for both accident rate and percentage of TOTAL is presented in Table A18. The aircraft are ordered according to the sum of the (signed) Chi-square values calculated for both rate and percentage for fatal accidents only. If the examples are selected from near the top or bottom of the list, one may be confident that a relatively "good" case is not really a relatively "bad" one and vice-versa.

Also presented in Table A18 is the actual number of stall plus mush accidents for the period, to be compared in the next two columns with the number of accidents which would be predicted on the basis of the summary group (32) rate and percentage. For example, the Cessna 182 had 13 fatal accidents, whereas if it had the same rate or percentage of TOTAL accidents as the Group 32 mean, the number would have been 40.7 or 32.9, respectively. The Piper PA-18, on the other hand, had more than twice the number of fatal stall/mush accidents than would have been predicted according to the Group 32 mean.

In Figure A11 the Chi-square value calculated on the basis of the stall/much fatal accident rate, and the accident rate itself, are shown for each airplane. The dashed vertical line represents the mean rate for Group 32, while the horizontal lines labeled 0.1% and 0.5% mark the cut-off points for the two Chi-square tests (3.841 and 10.827). For several of the high accident rate airplanes the Chi-square value is so high that it is extremely unlikely that the observed differences occurred by chance.

TABLE A18. 31 SINGLE-ENGINE AIRCRAFT RANKED BY CHI-SQUARE TEST FOR STALL + MUSH ACCIDENTS

			NUMBER OF STALL + MUSH ACCIDENTS (AS 1^{st} OR 2^{nd} TYPE)					
			FATAL:			ALL:		
				PREDICTED BY:			PREDICTED BY:	
RANK3	GR. #	SHORT NAME	ACTUAL NUMBER	RATE	%OF TOTAL	ACTUAL NUMBER	RATE	%OF TOTAL
1	14	C-182	13	40.7	32.9	63	201.0	168.8
2	26	CHEROKEE	52	79.6	70.5	270	393.1	331.2
3	11	C-172	44	75.1	52.7	240	370.6	245.5
4	17	C-210	5	12.8	15.7	14	63.3	68.1
5	25	COMANCHE	15	19.1	30.7	66	94.4	126.0
6	9	C-150	75	110.8	59.4	427	547.3	386.7
7	12	C-175	1	5.0	5.5	24	24.8	23.5
8	13	C-180	6	12.4	10.4	47	61.3	76.9
9	27	CHER-6	6	9.3	10.0	25	45.9	36.2
10	5	BONANZA	42	41.0	52.5	135	202.4	165.9
11	6	BELLANCA	2	2.5	4.1	8	12.5	19.5
12	22	PA-12	2	3.6	3.2	31	17.6	26.7
13	15	C-185	2	3.6	3.1	9	18.0	17.7
14	16	C-206	6	8.5	5.1	15	42.2	28.8
15	31	STINSON	5	3.9	7.4	47	19.3	45.2
16	24	TRIPACER	22	21.6	24.6	97	106.7	152.1
17	2	ERCOUPE	6	5.3	7.5	43	26.4	45.5
18	10	C-170	9	8.4	9.8	80	41.4	64.2
19	8	C-140	13	9.7	9.4	86	47.9	89.3
20	19	MOONEY	30	22.0	29.6	91	108.7	106.8
21	20	NAVION	8	3.9	9.7	27	19.4	27.4
22	4	B-23	15	9.9	9.7	83	49.0	71.1
23	29	TAYLORCR	10	3.3	7.8	64	16.1	30.6
24	18	C-177	14	5.8	7.4	88	28.5	43.1
25	1	AERON.11	6	1.4	2.8	29	6.9	14.6
26	28	LUSCOMBE	16	4.3	9.1	72	21.3	65.9
27	3	YANKEE	11	2.4	5.4	36	11.6	17.5
28	30	SWIFT	10	1.3	5.1	50	6.3	23.0
29	21	CUB	29	7.4	14.7	158	36.6	57.3
30	7	CITABRIA	44	13.8	24.9	196	68.0	116.6
31	23	PA-18	40	10.4	18.3	138	51.3	67.7
	32	GR.#32	559	559	559	2759	2759	2759

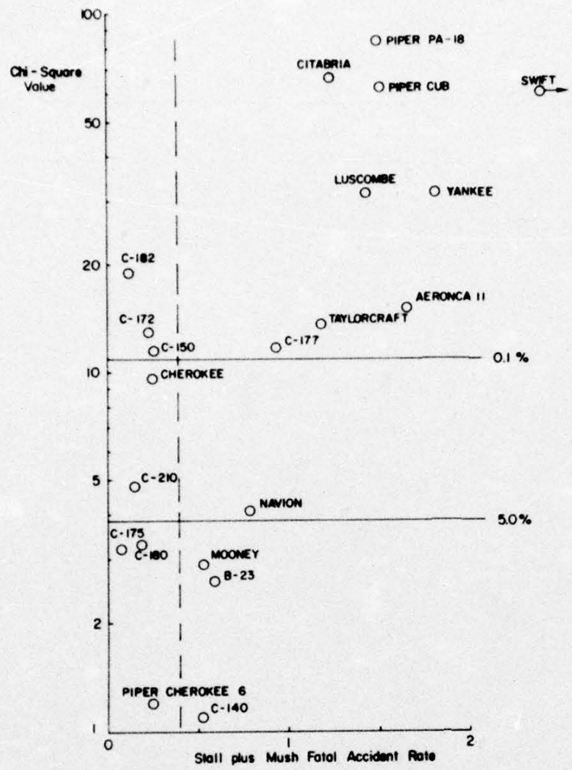


Figure A11. Chi-square Test Value versus Stall plus Mush Fatal Accident Rate for Group 32 Airplanes.

REFERENCES - APPENDIX A

A1. Silver, B. W., Statistical Analysis of General Aviation Stall Spin Accidents, SAE Paper 760480, April 1976.

A2. Special Study - General Aviation Stall/Spin Accidents 1967-1969, NTSB Report AAS-72-8, September 1972.

A3. "General Aviation Activity Survey, 1972," Federal Aviation Administration, July 1974.

APPENDIX B

TYPES OF ACCIDENTS

The purpose of the appendix is to give a short description of the NTSB method of defining accident types.

The phrase "accident type" refers to what happened. Examples are "groundloop," "stall," and "undershoot." There may be up to two accident types assigned for each accident. The two accident types, when used, are sequential in time. For example, the first type might be "engine failure or malfunction," followed by a second type, "stall." This would mean that the pilot had trouble with his engine and subsequently stalled the aircraft (perhaps in a forced landing attempt).

There are 59 different codes which the NTSB has defined for accident types. Only the stall-related are of primary interest in this report. The following accident type descriptions are abstracted in part from NTSB coding manuals.

STALL: Stall occurs when the wing angle of attack is too great to maintain smooth air flow. An accident occurs if the pilot does not "recover" before striking the ground. That event is counted in this accident type. A second accident type is not required; the collision with the ground is implicit. During the landing phase, a stall which results in a hard landing is coded as a "hard landing" rather than a "stall." Examples of occurrence: stalled while attempting to clear an obstruction; pull-up from a low pass; stalled from steep turn after buzzing friend's house; stalled during turn to final approach.

MUSH: The mush is a form of near-stall in which the airplane staggers along at a high angle of attack, generally on the back side of the power required curve. For most lightplanes with their modest or high power loadings, only a reduction in the angle of attack will allow acceleration out of this condition. Low altitude or obstacles may discourage this choice. This accident is generally (70%) a takeoff accident. Since it occurs at low speed and low altitude, it is seldom fatal, but it does cause substantial damage to the aircraft. Most mush accidents (99%) are blamed on the pilot. The accident is more likely with short fields and high density altitude. Examples of occurrence: takeoff in overloaded aircraft, especially uphill or downwind; pilot unable to climb with full flaps after an aborted landing; pilot attempted to climb in the lee of a mountain ridge.

SPIN: A spin is a self-propelling rotary motion ("autorotation") superimposed on a stall. In light aircraft, each turn of a spin typically takes only a few seconds and results in the loss of many hundred feet of altitude. The large sink rate of the spin makes this accident fatal in approximately 70% of the cases. Most spins (about two-thirds) occur in the in-flight phase of flight and are often associated with aerobatics, buzzing, or low flight. Fewer than 20% occur in each of takeoff and landing phases.

SPIRAL: The spiral is a tight turn superimposed on a dive. It is often associated with loss of horizontal reference. In appearance similar to the spin, the two differ in that the spiral does not involve significant

aerodynamic stall. Nevertheless, it is often included in stall-related accidents because it may be difficult to differentiate between the spin and the spiral after an accident has occurred. The distinction will generally be that the spin has almost no net forward motion at impact, while the spiral does have forward motion. The spiral is fatal in approximately 37% of such accidents. This number of fatal spirals is less than one-tenth of the number of fatal spins, thus no great statistical error is made in combining these two accident types.

When a stall-related accident is listed as a second type, it is often preceded by an "engine failure or malfunction" as a first type. This accident type is described here:

ENGINE FAILURE OR MALFUNCTION: An engine failure of itself is not considered an accident; it must be followed by a second accident type. Undoubtably many engine failures occur which never show up as accidents. Those which do add up to about 17% of general aviation accidents. Most engine failures are also blamed on the pilot. Among the most common errors: fuel starvation (selected the wrong tank), fuel exhaustion (ran out of gas), and improper use of carburator heat. Actual mechanical failure occurs only in about 40% of engine failures reported by the NTSB. The phrase "TRUE ENGINE FAILURE" is used to denote engine failures which were caused by actual failure of some part of the powerplant (rather than pilot error).

In this report the use of the word TOTAL in capital letters always refers to the total of all accident types, whether stall-related or not. There are two categories under TOTAL and these are FATAL (fatal accidents only) and ALL (fatal plus nonfatal accidents).

APPENDIX C

AIRCRAFT GROUPS

GR. #	SHORT NAME	MANUFACTURER NAME AND MODEL	FAA CODE:	NTSB CODE:	(1975) NUMBER OF ACTIVE AIRCRAFT
1	AERON.11	Aeronca 11	19-11	3-8,3-10	665
2	ERCOUPE	Ercoupe 415, Forney F-1, Alon A2, Mooney M10	42-1,-2,-3,-4, -5,-7;54-1; 587-20	63-1,-2	1968
3	YANKEE	Grumman American AA-1 (Excludes AA-5)	63-6,-7,-8, -12,-20	56-3	887
4	B-23	Beech 23, 19, 24 ("Musketeer", etc.)	115-12	22-25	1739
5	BONANZA	Beech 33, 35, 36 ("Bonanza", Debonair")	115-14,-15,-16	22-19,-20	8071
6	BELLANCA	Bellanca 14-19, 17-30, 17-31	*122-4; 308-1; 458-8	56-1,-4	1015
7	CITABRIA	Champion, Aeronca, Bellanca Model 7	*122-4,-5,-6 -7; 211-1	3-12	3974
8	C-140	Cessna 120, 140, 140A	207-14,-16	39-10,-11	3017
9	C-150	Cessna 150	207-18	39-12	12915
10	C-170	Cessna 170	207-23	39-13	2541
11	C-172	Cessna 172	207-24	39-14	13927
12	C-175	Cessna 175, P172D	207-25,-22	39-15	1544
13	C-180	Cessna 180	207-26	39-16	2315
14	C-182	Cessna 182	207-27,-58	39-17	8342
15	C-185	Cessna 185	207-28	39-26	621
16	C-206	Cessna 206	207-33	39-29	1431
17	C-210	Cessna 210, 205	207-34,-32	39-19	2775
18	C-177	Cessna 177 "Cardinal" (Exclude 177RG)	**207-37	39-33	1431
19	MOONEY	Mooney M20 ("Mark 21",etc.)	587-2,-3	101-2,-3	4181
20	NAVION	Navion	615-1	107-1	1204
21	CUB	Piper J-3, L-4, PA-11	710-5,-11	124-4,-5,-6, -7,-8	2766
22	PA-12	Piper PA-12 ("Super Cruiser")	710-12	124-15	1077
23	PA-18	Piper PA-18, L-21, PA-19, ("Super Cub")	710-18,-19	124-20,-21	2417

*FAA Code 122-4 must be further subdivided between BELLANCA and CITABRIA by name of model.
**Exclude Cessna 177RG (retractable gear) from FAA Code 207-37.

APPENDIX C (Continued)

GR. #	SHORT NAME	MANUFACTURER NAME AND MODEL	FAA CODE:	NTSB CODE:	(1973) NUMBER OF ACTIVE AIRCRAFT
24	TRIPACER	Piper PA-22 ("Tripacer", "Colt")	710-22	124-23	4733
25	COMANCHE	Piper PA-24 ("Comanche")	710-24	124-25	3449
26	CHEROKEE	Piper PA-28 ("Cherokee")	710-28	124-28	14180
27	CHER-6	Piper PA-32 ("Cherokee Six")	710-32	124-30	1769
28	LUSCOMBE	Luscombe 8 ("Silvaire")	819-1	89-3	1763
29	TAYLORCR	Taylorcraft B, L-2	885-3; 923-9	157-5,-6,-7	1355
30	SWIFT	Globe GC-1 ("Swift")	923-1	162-1	538
31	STINSON	Stinson 108	923-4	162-2	1746
32	GR.#32	All aircraft GR.#1 through GR.#31 (NO crop control)	all above	all above	110366
33	GR.#33	Crop control accidents only for Group 32 aircraft	all above	all above	(110366)
34	GR.#34	All general aviation, fixed-wing, single- or twin-engine aircraft			
35	GR.#35	All general aviation, fixed-wing, signle-engine aircraft			
36	GR.#36	All general aviation, fixed-wing, twin-engine aircraft			

APPENDIX D

SUMMARY OF STALL BEHAVIOR

I. CESSNA 150L N19020

A. WINGS LEVEL, BALL CENTERED

1. POWER OFF, FLAPS 0^{o}

Aft C.G. - nose bob, nose slice back and forth, repeated pitch breaks if wheel held back; roll control good with ailerons, left roll off if deceleration fast
Forward C. G. - no break; roll control with ailerons good but with rudder poor

2. POWER OFF, FLAPS DOWN

Aft C. G. - no roll off, oscillates if wheel held full back; can hold wings level with vigorous aileron movement
Forward C. G. - no break

3. POWER MAXIMUM, FLAPS 0^{o}

Aft C. G. - roll off either direction, nose slice, not confident about picking up wing
Forward C. G. - left roll off first time, right roll off second time

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - left roll off; if wheel immediately put forward can control roll
Forward C. G. - left roll off, nose oscillation

B. TWENTY DEGREE BANK, BALL CENTERED

1. POWER OFF, FLAPS 0^{o}

Aft C. G. - no roll off
Forward C. G. - no roll off, pitch oscillation in left turn, slight break at top; more pronounced in right turn but no full stall, roll control positive; left roll off in right turn when deceleration fast

2. POWER OFF, FLAPS DOWN

Aft C. G. - no roll off
Forward C. G. - no roll off, pitch oscillation (nose drops 10^{o} back up to 0^{o}); roll control positive

3. POWER MAXIMUM, FLAPS 0^{o}

Aft C. G. - right roll off in both left and right turn
Forward C. G. - tendency for right roll off in left turn, left roll off in right turn; roll control OK

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - right roll off in left turn, left roll of in right turn
Forward C. G. - right roll off in left turn, left roll off in right turn; roll control good, can hold in stall

I. <u>CESSNA 150L</u> (continued)

C. <u>WINGS LEVEL, NO RUDDER USED</u>

1. <u>POWER OFF, FLAPS 0^{o}</u>

Aft C. G. - no roll off, lots of yaw, can hold wings level
Forward C. G. - no roll, ball centered, good control

2. <u>POWER OFF, FLAPS DOWN</u>

Aft C. G. - no roll off initially but if trying to stop yaw with aileron can cause left roll off
Forward C. G. - no roll off, can't completely stall

3. <u>POWER MAXIMUM, FLAPS 0^{o}</u>

Aft C. G. - left roll off; can prevent roll off only if wheel back pressure released or not increased
Forward C. G. - left roll off, ball 3/4 right

4. <u>POWER MAXIMUM, FLAPS DOWN</u>

Aft C. G. - left roll off; cannot hold even when back pressure released immediately and wheel pushed forward
Forward C. G. - left roll, spin entry to left; can hold with aileron only to beginning of warning horn.

II. <u>CESSNA 182 N7374Q</u>

A. <u>WINGS LEVEL, BALL CENTERED</u>

1. <u>POWER OFF, FLAPS 0^{o}</u>

Aft C. G. - roll control good, no pitch break from slow decel.
Forward C. G. - no break, nose bob, roll control good

2. <u>POWER OFF, FLAPS DOWN</u>

Aft C. G. - nose bob, roll control adequate
Forward C. G. - nose bob, roll control OK

3. <u>POWER MAXIMUM, FLAPS 0^{o}</u>

Aft C. G. - roll control good, no pitch break from slow decel.
Forward C. G. - roll control good, no pitch break from slow decel.

4. <u>POWER MAXIMUM, FLAPS DOWN</u>

Aft C. G. - roll control acceptable
Forward C. G. - roll control good, no pitch break from slow decel.

B. <u>TWENTY DEGREE BANK, BALL CENTERED</u>

1. <u>POWER OFF, FLAPS 0^{o}</u>

Aft C. G. - rolls right in left turn, rolls right and nose bob in right turn; no uncontrollable tendencies
Forward C. G. - no break, tends to roll right; but controllable

II. CESSNA 182 (continued)

B. TWENTY DEGREE BANK, BALL CENTERED (continued)

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose bob and no roll off in left turn, right roll off in right turn; rocking chair motion
Forward C. G. - nose bob, tends to roll right, controllable

3. POWER MAXIMUM, FLAPS 0^{o}

Aft C. G. - tends to roll right, roll control good, attitude very high
Forward C. G. - rolls right from left and right turns; controllable

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - not much roll tendency, lots of buffet but no pitch problem
Forward C. G. - no pitch break, roll controllable with aileron

C. WINGS LEVEL, NO RUDDER USED

1. POWER OFF, FLAPS 0^{o}

Aft C. G. - slight right roll, rocking chair motion; can hold wings level ($\pm 5^{o}$); can track heading ($\pm 15^{o}$)
Forward C. G. - no break, slight nose bob; can hold wings level, can track heading

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose bob, rocking chair motion; bank angle controllable, can track heading ($\pm 15^{o}$)
Forward C. G. - nose bob, then breaks down 10^{o}; some nose slice, can hold wings level, can track heading ($\pm 10^{o}$)

3. POWER MAXIMUM, FLAPS 0^{o}

Aft C. G. - ball moves 1 right but airplane rolls right; can hold wings level with full left aileron but yaws right
Forward C. G. - no bad roll off, can hold wings level ($\pm 15^{o}$), heading control poor; controls too heavy to hold long with one hand; ball moves 1/2 to 3/4 right

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - rolls right, can hold with aileron
Forward C. G. - no bad roll off, cannot hold heading to $\pm 30^{o}$; elevator very heavy, ball moves 1/2 right

III. CESSNA 177 N124KA

A. WINGS LEVEL, BALL CENTERED

1. POWER OFF, FLAPS 0^{o}

Aft C. G. - roll control good except right at break when cannot hold wings level ($\pm 10^{o}$); nose oscillates in pitch ($\sim 10^{o}$)
Forward C. G. - nose bob, wing drops either way, can hold with rudder

III. CESSNA 177 (continued)

A. WINGS LEVEL, BALL CENTERED (continued)

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose bob
Forward C. G. - nose bob; roll control good

3. POWER MAXIMUM, FLAPS 0^{o}

Aft C. G. - can catch right roll at break; further into stall right roll off, coordinated aileron and rudder needed to hold wings level
Forward C. G. - roll control good

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - left roll off, cannot stop with rudder or aileron
Forward C. G. - roll off, roll control fair to good

B. TWENTY DEGREE BANK, BALL CENTERED

1. POWER OFF, FLAPS 0^{o}

Aft C. G. - wing rock, nose pitches down, can hold bank with coordinated rudder and aileron
Forward C. G. - tendency for right roll off in left turn, left roll off in right turn; roll control good with ailerons

2. POWER OFF, FLAPS DOWN

Aft C. G. - pitch oscillation, not controllable, can keep upright or in bank but sloppy
Forward C. G. - gentle nose oscillation ($\pm 15^{o}$), no roll off, roll control good

3. POWER MAXIMUM, FLAPS 0^{o}

Aft C. G. - right roll off in right turn, cannot hold with ailerons
Forward C. G. - right roll off, can hold with ailerons

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - left roll off, can hold with aileron if back pressure relaxed slightly
Forward C. G. - yaw and gentle left roll in left turn, left roll to level in right turn; right roll in left turn if accelerated

C. WINGS LEVEL, NO RUDDER USED

1. POWER OFF, FLAPS 0^{o}

Aft C. G. - pitch break; not much roll, can hold wings level but cannot track heading ($\pm 30^{o}$)
Forward C. G. - left roll off, controllable with ailerons; nose holds position; can hold wings level but sloppy ($\pm 5^{o}$), can track heading but sloppy (± 10-15^{o})

III. CESSNA 177 (continued)

C. WINGS LEVEL, NO RUDDER USED (continued)

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose oscillation, can hold wings level with fairly vigorous aileron movement; lost it in left departure trying to hold heading

Forward C. G. - nose oscillation ($\pm 5^{o}$), slightly right roll, can catch with aileron, can hold wings level, tracking heading poor ($\pm 15^{o}$)

3. POWER MAXIMUM, FLAPS 0^{o}

Aft C. G. - tendency for left departure, can catch roll with full right aileron if no further back pressure used; ball moves 2 right

Forward C. G. - rolls left, can catch with ailerons but control over bank and heading gross; ball moves full right side

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - left departure, cannot hold with ailerons

Forward C. G. - left departure, ball moves 1-1/2 right

IV. CITABRIA 150 N87108

A. WINGS LEVEL, BALL CENTERED

1. POWER OFF

Aft C. G. - roll control OK if coordinated, aileron alone not good

Forward C. G. - ailerons effective to just above stall; increasing back pressure hold nose in position; roll off either direction, aileron alone will not hold it, coordinated controls will

2. POWER MAXIMUM

Aft C. G. - roll control OK if coordinated

Forward C. G. - nose drop; right wing drop; cannot hold with left aileron unless back pressure relaxed slightly

B. TWENTY DEGREE BANK, BALL CENTERED

1. POWER OFF

Aft C. G. - at one trim speed rolls wings level, at another trim speed rolls off left in right turn; rolls off right in left turn, roll control poor, need rudder

Forward C. G. - no roll at break, then right roll in left turn; no roll at break then left roll and wing rock in right turn

2. POWER MAXIMUM

Aft C. G. - at one trim speed rolls back to wings level in left turn, rolls left unless back stick released in right turn; at another trim speed rolls right in left turn, rolls left in right turn, roll control poor

Forward C. G. - small bank excursions can be held with aileron; if coordinated controls used not much happens

IV. CITABRIA 150 (continued)

C. WINGS LEVEL, NO RUDDER NEEDED

1. POWER OFF

Aft C. G. - rolls right, nose pitches immediately after, can hold wings level for a bit but big aileron inputs cause yaw; can track heading but will eventually roll off right; ball moves 1/2 right

Forward C. G. - right roll off, if held just at break then can control roll with aileron for a while; ball moves 3/4 left, left bank needed to track heading

2. POWER MAXIMUM

Aft C. G. - left roll off, nose drop, plenty of stick left at break; hangs on surprisingly well but could get violent departure easily

Forward C. G. - rolls left, cannot hold with rudder, ball moves 1/2 right; 5^{o} right bank to track heading

V. GRUMMAN AMERICAN AA-1 YANKEE N5738L

A. WINGS LEVEL, BALL CENTERED

1. POWER OFF, FLAPS 0^{o}

Aft C. G. - nose bob, adequate roll control

Forward C. G. - gentle nose bobs, good roll control

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose bob, adequate roll control

Forward C. G. - nose bob, adequate roll control

3. POWER MAXIMUM, FLAPS 0^{o}

Aft C. G. - wing rock; roll control good if coordinated

Forward C. G. - some nose bob, good roll control

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - nose bob, wing rock, control good

Forward C. G. - nose bob, good roll control

B. TWENTY DEGREE BANK, BALL CENTERED

1. POWER OFF, FLAPS 0^{o}

Aft C. G. - sharp left roll and pitch down in left turn, caught with rudder

Forward C. G. - wing rock, rapid break left, and pitch down in left turn; little wing rock and left roll in right turn

2. POWER OFF, FLAPS DOWN

Aft C. G. - rolls back level

Forward C. G. - rolls left and then pitches; can aggravate with aileron and get right roll

V. GRUMMAN AMERICAN AA-1 YANKEE (continued)

B. TWENTY DEGREE BANK, BALL CENTERED (continued)

3. Aft.C. G. - rolls back level; rapid left roll off with fixed controls in right turn; vigorous rudder helpful but cannot hold full back stick

Forward C. G. - rolls left followed by pitch

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - rolls left with fixed controls; can stop roll with rudder but not with aileron alone

Forward C. G. - rolls left, can hold with vigorous right rudder; nose pitches down, can aggravate into right roll

C. WINGS LEVEL, NO RUDDER USED

1. POWER OFF, FLAPS 0^{o}

Aft C. G. - lot of buffet; held wings level and heading with small aileron inputs for a while, then sharp left wing down followed immediately by pitch - very quick

Forward C. G. - yaws and rolls right, pitches down, left roll second time; nose and roll oscillation build in amplitude

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose bob, hold for a while with small control inputs, then lost it to the left

Forward C. G. - yaws and then rolls right, nose drop (10^{o}), cannot hold

3. POWER MAXIMUM, FLAPS 0^{o}

Aft C. G. - left nose slice; cannot hold with aileron, ball moves 1/2 right

Forward C. G. - yaws and rolls left; cannot hold with full aileron, will roll violently left; ball moves 1/2 right

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - left roll off, cannot hold wings level or heading with aileron

Forward C. G. - rolls and yaws left, cannot hold with aileron; ball moves 1/4 right

VI. GRUMMAN AMERICAN AA-1B TRAINER N8982L

A. WINGS LEVEL, BALL CENTERED

1. POWER OFF, FLAPS 0^{o}

Aft C. G. - right roll off, can hold with rudder

2. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - roll control good, especially if aileron and rudder coordinated

3. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - roll control fair, can control bank with combined aileron and rudder with stick full back

NOTE: Complete series was not carried out with this airplane.

VII. PIPER CHEROKEE 140 N422FL

A. WINGS LEVEL, BALL CENTERED

1. POWER OFF, FLAPS 0°

Aft C. G. - pitch oscillation, roll control poor, need conscious rudder coordination
Forward C. G. - nose oscillation

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose drop, oscillation; wallows - small roll oscillation, roll control adequate
Forward C. G. - gentle nose bob

3. POWER MAXIMUM, FLAPS 0°

Aft C. G. - pitch oscillation; roll control adequate
Forward C. G. - no break, roll control adequate

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - nose bob starts pronounced pitch oscillations; roll control adequate
Forward C. G. - left wing drop, can hold with aileron

B. TWENTY DEGREE BANK, BALL CENTERED

1. POWER OFF, FLAPS 0°

Aft C. G. - pitch oscillation; no roll, roll control good
Forward C. G. - no break, nose bob; little roll oscillation controllable with aileron

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose bob; no roll off in left turn, right roll off in right turn, roll control good
Forward C. G. - nose bob, builds up to sharp break (.3 g), roll control adequate

3. POWER MAXIMUM, FLAPS 0°

Aft C. G. - pitch oscillation; no roll off, roll control good
Forward C. G. - no break, nose bob; roll control good

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - rolls left in both left and right turn, can level wings with aileron (sometimes difficult); nose bob violent (>5°)
Forward C. G. - no break, pitch oscillation; rolls off left in both left and right turn, can hold with aileron

C. WINGS LEVEL, NO RUDDER USED

1. POWER OFF, FLAPS 0°

Aft C. G. - nose bob; wallows in roll, tends to roll right, ball moves 1/4 left; can hold with a lot of left aileron; some nose slice and sloppy performance in tracking heading

VII. PIPER CHEROKEE 140 (continued)

C. WINGS LEVEL, NO RUDDER USED (continued)

1. POWER OFF, FLAPS 0^{o} (continued)

Aft C. G. - requires full left aileron to hold wings level, roll control poor; right roll and nose drop while trying to track heading

Forward C. G. - pitch oscillation; no roll problems, ball stays centered; rolls better right than left and some adverse yaw in tracking heading

2. POWER OFF, FLAPS DOWN

Aft C. G. - small pitch oscillation, can hold heading with aileron

Forward C. G. - pitch oscillation; no roll problems except reluctance to bank left

3. POWER MAXIMUM, FLAPS 0^{o}

Aft C. G. - nose bob; no roll off, can hold heading with aileron, ball moves 1/4 right

Forward C. G. - nose bob; roll control adequate, ball less than 1/4 right, can hold heading with aileron

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - left roll off, cannot hold wings level with aileron if back pressure continued; ball 1/3 right

Forward C. G. - incipient yaw, left roll, can hold with aileron, ball 1/3 right

APPENDIX E

STALL-RELATED PORTIONS OF FAR PART 23

23.3 Airplane categories

(a) The normal category is limited to airplanes intended for nonacrobatic operation. Nonacrobatic operation includes

(1) Any manuever incident to normal flying;
(2) Stalls (except whip stalls); and
(3) Lazy eights, chandelles, and steep turns, in which the angle of bank is not more than 60^{o}.

(b) The utility category is limited to airplanes intended for limited acrobatic operation. Airplanes certificated in the utility category may be used in any of the operation covered under paragraph (a) of this section and in limited acrobatic operations. Limited acrobatic operation includes

(1) Spins (if approved for the particular type of airplane); and
(2) Lazy eights, chandelles, and steep turns, in which the angle of bank is more than 60^{o}.

(c) The acrobatic category is limited to airplanes intended for use without restrictions other than those shown to be necessary as a result of required flight tests.

(d) Small airplanes may be certificated in more than one category if the requirements of each requested category are met.

23.49 Stalling speed.

(a) V_{s_o} is the stalling speed, if obtainable, or the minimum steady speed, in knots (CAS), at which the airplane is controllable with the -

(1) Engines idling, throttles closed (or at not more than the power necessary for zero thrust at a speed not more than 110 percent of the stalling speed);
(2) Propellers in the takeoff position;
(3) Landing gear extended;
(4) Wing flaps in the landing position;
(5) Cowl flaps closed;
(6) Center of gravity in the most unfavorable position within the allowable landing range; and
(7) Weight used when V_{s_o} is being used as a factor to determine compliance with a required performance standard.

(b) V_{s_o} at maximum weight may not exceed 61 knots for -

(1) Single-engine airplanes; and
(2) Multiengine airplanes of 6,000 pounds or less maximum weight that cannot meet the minimum rate of climb specified in § 23.67(b) with the critical engine inoperative.

(c) V_{s_1} is the calibrated stalling speed, if obtainable, or the minimum steady speed, in knots, at which the airplane is controllable, with the -

(1) Engines idling, throttles closed (or at not more than the power necessary for zero thrust at a speed not more than 110 percent of the stalling speed);
(2) Propellers in the takeoff position;
(3) Airplane in the condition existing in the test in which V_{s_1} is being used; and
(4) Weight used when V_{s_1} is being used as a factor to determine compliance with a required performance standard.

(d) V_{s_o} and V_{s_1} must be determined by flight tests, using the procedure specified in § 23.201.

23.143 General.

(a) The airplane must be safely controllable and maneuverable during -

(1) Takeoff;
(2) Climb;
(3) Level flight;
(4) Dive; and
(5) Landing (power on and power off) with the wing flaps extended and retracted.

(b) It must be possible to make a smooth transition from one flight condition to another (including turns and slips) without exceptional piloting skill, alertness, or strength, and without danger of exceeding the limit load factor, under any probable operating condition (including, for multi-engine airplanes, those conditions normally encountered in the sudden failure of any engine).

(c) If marginal conditions exist with regard to required pilot strength, the "strength of pilots" limits must be shown by quantitative tests. In no case may the limits exceed those prescribed in the following table:

Values in pounds of force as applied to the control wheel or rudder pedals	Pitch	Roll	Yaw
(a) For temporary application:			
Stick	60	30	--------
Wheel (applied to rim)	75	60	--------
Rudder pedal			150
(b) For prolonged application	10	5	20

23.201 Wings level stall.

(a) For an airplane with independently controlled roll and directional controls, it must be possible to produce and to correct roll by unreversed use of the rolling control and to produce and to correct yaw by unreversed use of the directional control, up to the time the airplane pitches.

(b) For an airplane with interconnected lateral and directional controls (2 controls) and for an airplane with only one of these controls, it must be possible to produce and correct roll by unreversed use of the rolling control without producing excessive yaw, up to the time the airplane pitches.

(c) The wing level stall characteristics of the airplane must be demonstrated in flight as follows: The airplane speed must be reduced with the elevator control until the speed is slightly above the stalling speed, then the elevator control must be pulled back so that the rate of speed reduction will not exceed one knot per second until a stall is produced, as shown by an uncontrollable downward pitching motion of the airplane, or until the control reaches the stop. Normal use of the elevator control for recovery is allowed after the pitching motion has unmistakably developed.

(d) Except where made inapplicable by the special features of a particular type of airplane, the following apply to the measurement of loss of altitude during a stall:

(1) The loss of altitude encountered in the stall (power on or power off) is the change in altitude (as observed on the sensitive altimeter testing installation) between the altitude at which the airplane pitches and the altitude at which horizontal flight is regained.
(2) If power or thrust is required during stall recovery the power or thrust used must be that which would be used under the normal operating procedures selected by the applicant for this maneuver. However, the power used to regain level flight may not be applied until flying control is regained.

(e) During the recovery part of the maneuver, it must be possible to prevent more than 15 degrees of roll or yaw by the normal use of controls.

(f) Compliance with the requirements of this section must be shown under the following conditions:

(1) Wing Flaps: Full up, full down, and intermediate, if appropriate.
(2) Landing Gear: Retracted and extended.
(3) Cowl flaps: Appropriate to configuration.
(4) Power: Power or thrust off, and 75 percent maximum continuous power or thrust.
(5) Trim: 1.5 V_{s_1} or at the minimum trim speed, whichever is higher.
(6) Propeller: Full increase rpm position for the power off condition.

23.203 Turning flight and accelerated stalls.

Turning flight and accelerated stalls must be demonstrated in tests as follows:

(a) Establish and maintain a coordinated turn in a 30 degree bank. Reduce speed by steadily and progressively tightening the turn with the elevator until the airplane is stalled or until the elevator has reached its stop. The rate of speed reduction must be constant, and -

(1) For a turning flight stall, may not exceed one knot per second; and

(2) For an accelerated stall, be 3 to 5 knots per second with steadily increasing normal acceleration.

(b) When the stall has fully developed or the elevator has reached its stop, it must be possible to regain level flight without -

(1) Excessive loss of altitude;

(2) Undue pitchup;

(3) Uncontrollable tendency to spin;

(4) Exceeding 60 degree of roll in either direction from the established 30 degree bank; and

(5) For accelerated entry stalls, without exceeding the maximum permissible speed or the allowable limit load factor.

(c) Compliance with the requirements of this section must be shown with -

(1) Wing Flaps: Retracted and fully extended for turning flight and accelerated entry stalls, and intermediate, if appropriate, for accelerated entry stalls;

(2) Landing Gear: Retracted and extended;

(3) Cowl Flaps: Appropriate to configuration;

(4) Power: 75 percent maximum continuous power; and

(5) Trim: 1.5 V_{S_1} or minimum trim speed, whichever is higher.

23.207 Stall warning.

(a) There must be a clear and distinctive stall warning, with the flaps and landing gear in any normal position, in straight and turning flight.

(b) The stall warning may be furnished either through the inherent aerodynamic qualities of the airplane or by a device that will give clearly distinguishable indications under expected conditions of flight. However, a visual stall warning device that requires the attention of the crew within the cockpit is not acceptable by itself.

(c) The stall warning must begin at a speed exceeding the stalling speed by a margin of not less than 5 knots, but not more than the greater of 10 knots or 15 percent of the stalling speed, and must continue until the stall occurs.

23.251 Vibration and buffeting.

Each part of the airplane must be free from excessive vibration under any appropriate speed and power conditions up to at least the minimum value of V_D allowed in § 23.335. In addition, there may be no buffeting, in any normal flight condition, severe enough to interfere with the satisfactory control of the airplane, cause excessive fatigue to the crew, or result in structural damage. Stall warning buffeting within these limits is allowable.

23.1587 Performance information.

(a) <u>General</u>. For each airplane, the following information must be furnished:

(1) Any loss of altitude more than 100 feet, or any pitch more than 30° below flight level, occurring during the recovery part of the maneuver prescribed in § 23.201(b).

(2) The conditions under which the full amount of usable fuel in each tank can safely be used. This information must be in the Airplane Flight Manual (if provided) or on a placard.

(b) Airplanes of more than 6,000 pounds maximum weight. For each airplane of more than 6,000 pounds maximum weight, the following information must be furnished:

(1) The stalling speed, V_{s_o} at maximum weight

(2) The stalling speed, V_{s_1} at maximum weight and with landing gear and wing flaps retracted, and the effect upon this stalling speed of angles of bank up to 60°.

(3) The takeoff distance determined under § 23.51(a), the airspeed at the 50-foot height, the airplane configuration (if pertinent), the kind of surface used in the tests, and the pertinent information with respect to cowl flap position, use of flight-path control devices, and use of the landing gear retraction system.

(4) The landing distance determined under § 23.75(a), the airplane configuration (if pertinent), the kind of surface used in the tests, and the pertinent information with respect to flap position and the use of flight-path control devices.

(5) The steady rate of climb, determined under §§ 23.65(a), 23.67(a) (if appropriate) and 23.77(a), the airspeed, power, and, if pertinent, the airplane configuration.

(6) The calculated approximate effect on takeoff distance (subparagraph (3) of this paragraph), landing distance (subparagraph (4) of this paragraph), and steady rate of climb (subparagraph (5) of this paragraph), of variations in -

(i) Altitude from sea level to 8,000 feet; and

(ii) Temperature at these altitudes from minus 60° F, below standard to plus 40° F. above standard.

For skiplanes, a statement in the Airplane Flight Manual of the approximate reduction in climb performance may be used instead of complete new data for the skiplane configuration if -

(1) The landing gear is fixed in both landplane and skiplane configurations;

(2) The climb requirements are not critical; and

(3) The climb reduction in the skiplane configurations is small (30 to 50 feet per minute).

(c) Multiengine airplanes. For multiengine airplanes, the following information must be furnished:

(1) The loss of altitude during the one engine inoperative stall shown under § 23.205 (as measured from the altitude at which the airplane starts to pitch uncontrollably to the altitude at which level flight is regained) and the pitch angle during that maneuver. This information must be furnished -

(i) In the Airplane Flight Manual, for airplanes of more than 6,000 pounds maximum weight; and

(ii) On a placard, for airplanes of 6,000 pounds or less maximum weight.

(2) The best climb speed, or the minimum descent speed, with one engine inoperative.

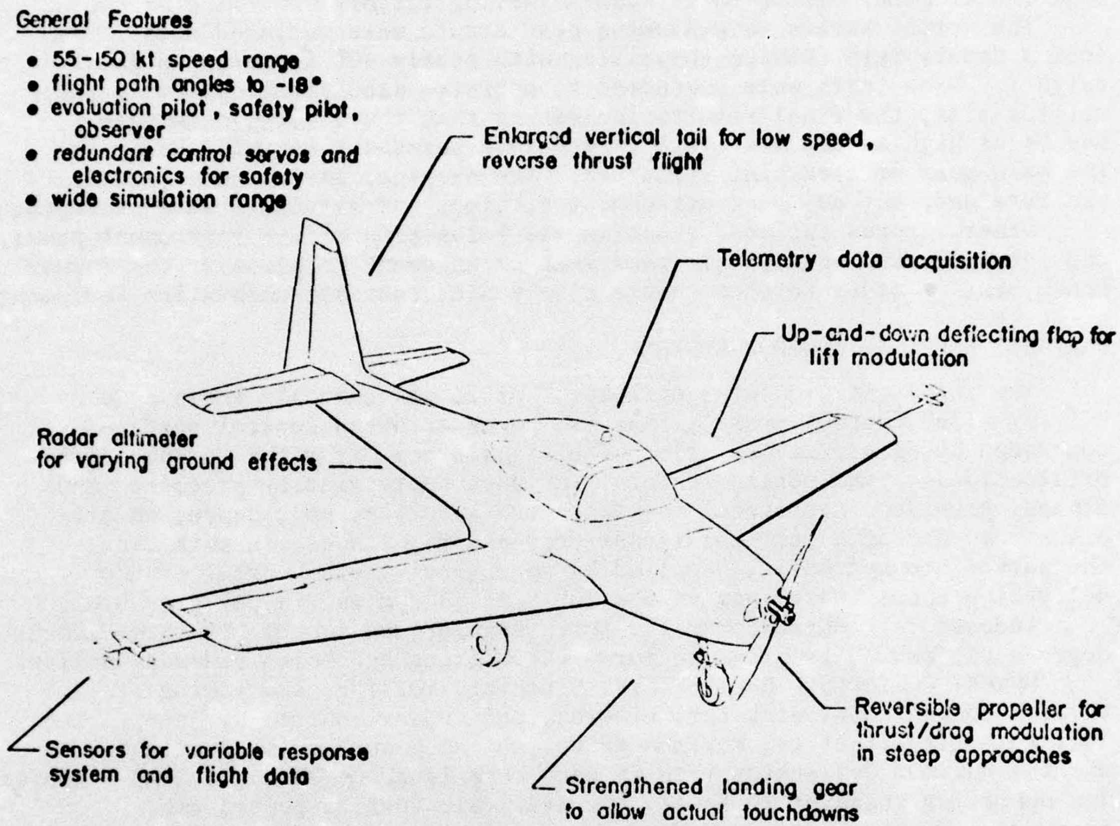
(3) The calculated approximate effect, on the steady rate of climb determined under § 23.67(b), of variation in -

(i) Altitude at sea level and at 8,000 feet in a standard atmosphere and cruise configuration; and

(ii) Temperature, at those altitudes from 60° F. below standard to 40° F. above standard.

APPENDIX F

THE IN-FLIGHT SIMULATOR



GENERAL DESCRIPTION

The In-Flight Simulator is based upon a modified Ryan Navion airframe; the power plant is a Teledyne-Continental IO-520B engine of 212.6 kilowatts (285 hp) driving a Hartzell reversing propeller. Gross weight has been increased from the original 12230 to 14010 N(2570 to 3150 lb).

Two externally noticeable airframe modifications were made to improve the research capability of the machine:

The flap hinging and actuation were changed to allow up, as well as down, deflection over a ±30 deg range, resulting in increased lift modulation authority and smaller drag changes compared to the previous 0-40 deg down-only flap. Aerodynamics of the basic airframe and of this flap arrangement were explored in the full-scale wind tunnel tests reported in References F1 and F2.

The second change was an increase in vertical tail area made necessary by serious losses in directional stability when operating in the reverse

thrust range. This was predicted by the wind tunnel tests and confirmed in flight. A 35.6 cm (14") extension, added to the base of the fin and bottom of the rudder, increased vertical tail area by nearly 50% and solved the problem, though at the expense of increased gust response and high rudder pedal forces in forward-thrusting flight.

The normal Navion main landing gear struts were replaced with those from a Camair twin (Navion conversion with nearly 40% increase in gross weight). Drop tests were conducted to optimize oleo strut inflation and orifice size, the final results indicating that the landing sink rate may be as high as 3.8 m/s (12.5 ft/s before permanent set will occur in the main gear or attaching structure. The original Navion nose gear strut was retained, but adjacent attachment fittings and structure were strengthened.

Other changes included redesign and reloaction of the instrument panel, and incorporation of a single rear seat arrangement in place of the former bench seat in order to accommodate electronics and instrumentation equipment.

VARIABLE RESPONSE CONTROL SYSTEM

The in-flight simulator utilizes what is now commonly known as a "fly-by-wire" control system, that is, power-actuated control surfaces commanded by electrical signals. The signals come from the various cockpit controllers and motion sensors, and when appropriately processed and summed, provide a net signal to each servo-actuator, and, hence, an airplane response of a particular character and magnitude. In this case, the servos are hydraulic, supplied by an engine-driven hydraulic pump delivering about .03 m^3/min at 5 x 10^6 N/m^2 (9 gpm at 725 psi pressure).

Independent control over the three angular and two of the three linear degrees of freedom is provided for - the missing one being sideways motion.

MOMENT CONTROLS - Control over pitching, rolling, and yawing are through conventional elevator, aileron, and rudder control surfaces. The full authority (that is, maximum travel) of each surface is available, and the maximum deflection rate in each case is about 70 deg/s. At a typical low operating speed of 70 knots, the available control powers are, respectively

Pitch: ±4.4 rad/s^2 (from trim)
Roll: ±4.1 rad/s^2
Yaw: ±1.3 rad/s^2

The presently available inputs to each of these controls are shown in Table F1.

NORMAL FORCE CONTROL - Independent control over normal acceleration is exercised through the Navion flap, modified to deflect up, as well as down, through a ±30 deg range. The upward motion provides increased lift modulation authority and tends to minimize the problems of drag and angle of zero lift changes. Actuation is hydraulic, with a maximum available surface rate of 110 deg/s. At 70 knots, the available authority is slightly more than ±5 g. Inputs presently available are shown in Table F2.

THRUST CONTROL - Thrust and drag modulation is by direct control of the blade pitch on the Hartzell reversing propeller, with the engine governed at 2300 ± 30 rpm by means of a tachometer feedback and throttle servoactuator. This system allows precise control over thrust and drag at flight path angles and/or deceleration rates well beyond the capability of the basic airplane with normal powerplant and closed throttle.

TABLE F1. INPUTS TO MOMENT CONTROLS

Channel	Input	Function Varied
Pitch	Control column displacement	Control sensitivity
	Thrust lever	Simulated moment due to thrust
	Column thumbwheel	Simulated DLC moment
	Radar altitude	Ground effect moment
	Airspeed	Speed stability
	Angle of attack	Static stability, pitching at stall
	Pitch attitude	Attitude hold sensitivity
	Pitch rate	Pitch damping
	Flap angle	Trim change from flap
	Flap rate	Moment from flap rate (Approximately $M_{\dot{\alpha}}$)
	Propeller pitch	Moment due to thrust
	Integral of column displacement	Rate command gain
	Simulated turbulence	Turbulence response
Roll	Wheel displacement	Control sensitivity
	Sideslip	Dihedral effect
	Roll rate	Roll damping
	Yaw rate	Roll due to yaw rate
	Rudder pedal displacement	Roll due to rudder
	Simulated turbulence	Turbulence
YAW	Rudder pedal displacement	Control sensitivity
	Sideslip	Directional stability
	Yaw rate	Yaw damping
	Roll rate	Yaw due to roll rate
	Wheel displacement	Yaw due to aileron
	Simulated turbulence	Turbulence response

TABLE F2. INPUTS TO NORMAL FORCE CONTROL

Input	Function Varied
Control column displacement	Lift due to control (simulates elevator lift, or direct lift control integrated with column)
Thrust lever displacement	Lift due to thrust, direct lift control integrated with throttle
Column thumbwheel	Separate direct lift control
Radar altitude	Ground effect lift; wind gradients
Airspeed	Lift change with speed
Angle of attack	Lift response to angle of attack, lift change at stall
Propeller pitch	Lift due to thrust
Simulated turbulence	Turbulence response

Propeller blade pitch is commanded through an electrohydraulic actuator connected to the mechanical-feedback servo which normally drives the reversing propeller when it is operating in its "Beta" mode. The blade pitch range presently used is +25 to -8 deg. With the engine governed at 2300 rpm, this provides performance ranging from modest climb (about 152 m/min or 500 ft/min) to steep descent ($\gamma \cong -18$ deg with V = 70 knots). Maximum blade actuation rate is about 20 deg/s. Inputs to the thrust/drag modulation system are shown in Table F3.

TABLE F3. INPUTS TO THRUST/DRAG MODULATION SYSTEM

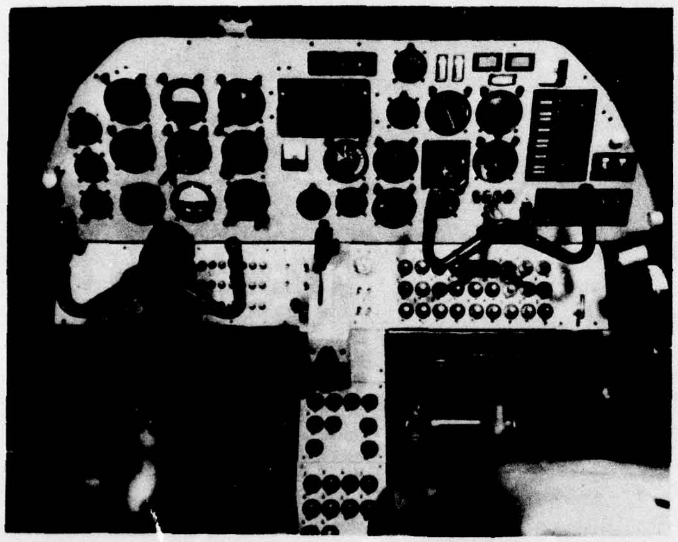
Input	Function Varied
Control column displacement	Drag due to control (simulated control surface drag; drag due to direct lift controls integrated with column)
Thrust lever displacement	Thrust command/throttle sensitivity
Column thumbwheel	Drag change due to direct lift control (separate controller)
Radar altitude	Ground effect drag change; wind gradients
Airspeed	Drag change with speed
Angle of attack	Drag change with angle of attack

INTERCONNECTS - It may be noted in the lists of inputs for the system (Tables F1-F3) that several coupling functions are provided. For some experiments, it is desirable to remove interacting effects in the basic airframe: lift and moment changes from thrust may be eliminated with interconnects between the propeller pitch sensor and the flap and elevator; and pitching moments due to flap angle and flap rate are countered with inputs to the elevator.

Simulated interacting effects are handled by using inputs from the various cockpit controllers: pitching moments and lift changes due to power are provided by interconnecting the elevator and the flap with the thrust lever (M_{δ_T}, L_{δ_T}); and lift and drag changes due to pitch controller displacement are represented in L_{δ_s} and D_{δ_s}. Other controllers may be similarly interconnected.

COCKPIT AND EVALUATION PILOT CONTROLS

The instrument panel and controls are shown at left. The right seat is occupied by the safety pilot who operates the normal Navion wheel and rudder and the power plant controls which have been relocated on the right side of the cockpit. Simulation system controls occupy the right side of the panel and the lower and middle consoles.



The evaluation pilot is seated on the left and provided with a standard flight instrument layout and conventional column, rudder, and throttle controls. Linear force gradients with no perceptable nonlinearities are incorporated. The gradients are ground adjustable by replacing springs. The values shown in Table F4 are currently being used.

TABLE F4. CURRENT VALUES FOR LINEAR FORCE GRADIENTS

Control	Force Gradient	Travel
Pitch column	7.9N/ cm (4.5 lb/in.)	7.6 cm forward (3 in.) 15.2 cm aft (6 in.)
Wheel	2.6N/cm (1.5 lb/in.)	±19.5 cm (±7.7 in.) ±80 deg
Pedal	44N/cm (25 lb/in.)	± 6.3 cm (±2.5 in.)
Throttle.	Adjustable friction	13.3 cm (5.25 in.)

Note: Three-axis trimming is provided

Special controls presently installed include the following:

1. Direct Lift: Thumbwheel separate controller; integrated with pitch column; integrated with throttle. Adjustable moment and drag interconnects are available.

2. Pitch attitude command proportional to column displacement, with trimmable attitude hold.

3. Pitch rate proportional to column displacement with attitude hold.

Attitude hold may also be selected with any of the direct lift system engaged.

DATA ACQUISITION

Data acquisition is through telemetry, with 43 channels available. Airframe motion parameters (linear accelerations, angular rates, attitude, and heading), control inputs, and performance measures, such as localizer and glide-slope deviation, are normally recorded. Altitude and altitude rate are available from the radar altimeter.

Correlation of touchdown time with the other parameters is obtained through a recording of fore-and-aft acceleration of the main landing gear strut; wheel spinup loads produce enough strut motion to record even very smooth landings.

SAFETY CONSIDERATIONS

By its very nature, landing research involves repeated exposure to minimum-speed, low-controllability situations, so special consideration was given to providing sufficient airframe strength and simulation system reliability to make the risk of damage from occasional hard touchdowns or control system failures acceptably low. The matter of strengthened landing gear was mentioned in an earlier section; the control system aspects will be discussed here.

SAFETY PILOT FUNCTION - Fundamental to the operation of an in-flight simulator is the concept that a safety pilot will continually follow the movements of the basic airplane controls, monitor the systems and the flight path, and be ready to disengage or override the evaluation pilot in case of a malfunction or unsafe condition. For disengaging, a disconnect switch on the control wheel is the primary cutout, with the main electrical and hydraulic controls providing secondary means of deactivating the system.

Manual override of the hydraulic servoactuators is possible for all controls except the flap. The force required is set through an adjustable poppet valve on each servo - 178 N(40 lb) being typical.

Warning of system failures is provided by a flashing master warning light on the upper edge of the instrument panel in front of the safety pilot, with individual channel disengage warning on a panel slightly lower and to the right.

REDUNDANT CONTROL CHANNELS - The elevator, aileron, and throttle systems incorporate redundant control channels. The philosophy here is that hard-over control inputs resulting from system failures are particularly dangerous in this low-speed, low-altitude situation, and should be guarded against if possible. With the redundant channels, any substantial error between the commanded and actual control position is detected, and a

switchover to a second servo is made. The evaluation pilot retains control during this process, but all inputs to the switched channel, except those from the control column, are eliminated, thus reducing the possibility that a defective transducer or signal path is causing the problem. Redundant sensors for the control input signal are incorporated; the other transducers are not duplicated. The fact that a channel has switched to the secondary servo is communicated to the safety pilot by the aforementioned warning lights, and he can then disengage the system and assume control.

The elevator is clearly critical with regard to failures which result in sudden full deflection, with the ailerons only slightly less so. Redundancy was incorporated in the throttle channel to reduce the possibility of a failure, which would apply power with the propeller blade pitch below the normal low-pitch stop, a condition which would overspeed the engine. Redundancy was not incorporated in the rudder or propeller pitch channels, because inadvertent disengages were felt to be less critical, and, since he follows pedal and Beta motions continuously, the safety pilot can very effectively override large-deflection failures. The flap channel was not duplicated because most failure modes are not hazardous - the surface trails aerodynamically at a 10 deg down position, and upon disengage, its return to this position from up-deflections is rapid. Down-flap deflections clearly pose no safety problem; up-flap hardovers could be hazardous due to the large lift loss, but this has proved to be a failure mode so instantly recognizable by the safety pilot that a disengage (with subsequent down-float of the flap) can be effected with very small altitude loss.

WAVEOFF AUTOMATION - To aid the safety pilot in recovering from an excessive sink rate situation, and "abort mode" system disengage can be used. Activated by pressing the disengage thumb switch, the flap travels at maximum rate to a 20 deg down position and power is automatically advanced to a climb setting; primary control reverts to the safety pilot. Using this system, recovery from a 70 kt, 6 deg approach (sink rate of 3.8 m/s or 12.5 ft/s) with a simulated up-flap failure can be made with less than 3 m (10 ft) altitude loss.

MODIFICATIONS TO PROVIDE A STALL SIMULATION

The simulation of the stall requires two interconnects, an angle of attack to flap interconnect and a stick displacement to elevator interconnect. The lift loss, or "g" break, of the stall is simulated with up-flap movement while the pitch break is obtained through the natural pitch response associated with flap motion combined with down elevator.

The angle of attack or stick position at which each surface began to deflect (stall onset) is variable along with the amount of surface movement per unit change of angle of attack or stick position (severity of the break). This permits the necessary nonlinear lift and pitching moment curves of the stall to be simulated at an angle of attack well below the real Navion stall angle of attack.

Two types of stall warning devices are available, a horn and light combination and a stick shaker. Either or both could be activated by the leading-edge tab-type sensor (Safe-Flight SC-150) or the angle of attack vanes on each wing tip.

The evaluation pilot may refer to any of three angle of attack indicators. These include a slow-fast meter (Safe-Flight-style horizontal scale), a Navy-style angle of attack indexer (chevrons and donut), and

a dial indicator with a scale of zero to one unit (Teledyne-type unit). The safety pilot's panel holds a dial angle of attack indicator with a scale of zero to thirty units.

LONGITUDINAL STABILITY DERIVATIVES

For a 70 kt approach condition the dimensional stability derivatives are the following:

$$(D_V - T_V) = 0.16 \ 1/\text{sec}$$
$$(D_\alpha - g) = -12 \ \text{ft/sec}^2/\text{rad}$$
$$L_V = 0.58 \ 1/\text{sec}$$
$$L_\alpha / V_o = 1.2 \ 1/\text{sec}$$
$$M_V = 0$$
$$M_\alpha = -6.1 \ \text{rad/sec}^2/\text{rad} \ \text{(nominal stable value)}$$
$$M_{\dot{\alpha}} = -0.82 \ 1/\text{sec}$$
$$M_{\dot{\theta}} = -1.7 \ 1/\text{sec}$$

REFERENCES

F1. Shivers, J. P., Fink, M. P., and Ware, G. M., "Full-Scale Wind-Tunnel Investigation of the Static Longitudinal and Lateral Characteristics of a Light Single-Engine Low-Wing Airplane," NASA TN D-5857, June 1970.

F2. Seckel, E. and Morris, J. J., "Full-Scale Wind Tunnel Tests of a Low-Wing, Single-Engine, Light Plane with Positive and Negative Propeller Thrust and Up and Down Flap Deflection," NASA CR-1783 and Princeton University Report 922, August 1971.

APPENDIX G

STALL/SPIN BIBLIOGRAPHY

STALL/SPIN GENERAL

1. Bramson, A.: "A Lack of Awareness," Flight International, April 12, 1973, p. 575

2. Collins, L.: "Safety in Flying," Air Facts, Vol. 6, No. 7, July 1943, pp. 51-82.

3. "General Aviation Stall/Spin Accidents 1967-1969," National Transportation Safety Board Report No. NTSB-AAS-72-8, September 13, 1972.

4. Miller, C. O., Alexander, P., and Jett, S.: "U.S. General Aviation Safety Record," SAE Paper No. 710397, Business Aircraft Meeting, March 24-26, 1971.

5. "Models, Varied Tails Aid Stall-Spin Work," Aviation Week and Space Technology, February 17, 1975, pp. 62-64.

6. Nial, J. A.: "Status of U.S. Navy Stall/Post Stall/Spin Flight Testing," AIAA Paper No. 72-787, 4th Aircraft Design, Flight Test, and Operations Meeting, August 7-9, 1972.

7. Silver, B. W.: "Statistical Analysis of General Aviation Stall/Spin Accidents," SAE Paper No. 760480, Business Aircraft Meeting, April 6-9, 1976.

8. "Special Study: A Report on Approach and Landing Accident Prevention Forum," National Transportation Safety Board Report No. NTSB-AAS-73-2, October 24-25, 1972.

9. "The Spin-proof Aeroplane?" Flight International, February 22, 1973, pp. 253-254.

10. "Stall/Spin Accidents," Federal Aviation Administration Aviation News, October 1973, pp. 4-5.

11. Woodcock, R. J. and Cord, T. J.: "Stall/Spin Seventy Years Later," Air University Review, Vol. 25, May-June 1974, pp. 25-36.

CHARACTERISTICS OF THE STALL

12. "Aircraft Stalling and Buffeting," Advisory Group for Aerospace Research and Development Lecture Series No. 74, February 1975.

13. "Analog Computer Program on PT-26 Longitudinal Stall Responses," Cornell Aeronautical Laboratory FRM No. 109, June 20, 1950.

AD-A039 223 PRINCETON UNIV N J FLIGHT RESEARCH LAB F/G 1/2
A STUDY OF LIGHTPLANE STALL AVOIDANCE AND SUPPRESSION.(U)
FEB 77 D R ELLIS, J STEINBERGER DOT-FA74WA-3480

UNCLASSIFIED FAA-RD-77-25 NL

2 OF 2
AD A039223

END
DATE FILMED
5-77

14. Bailly, E. C.: "Stalls," Air Facts, Vol. 7, No. 4, April 1944, pp. 48-54.

15. Campbell, G. and Bull, G.: "Determination of the Longitudinal Stall Dynamics of a PT-26 Airplane," Cornell Aeronautical Laboratory Report No. TB-498-F-2, February 24, 1950.

16. Campbell, G. and Bull, G.: "Progress in Stall Research," Paper presented at the Institute of the Aeronautical Sciences' Annual Summer Meeting, July 12-13, 1950, Preprint No. 294.

17. Campbell, G. and Whitcomb, D. W.: "Theoretical and Experimental Investigations of the Longitudinal Stall Dynamics of a Conventional Airplane," Cornell Aeronautical Laboratory Report No. TB-498-F-1, May 28, 1948.

18. Crimi, P.: "Dynamic Stall," Advisory Group for Aerospace Research and Development AGARDograph No. 172, November 1973.

19. "Fluid Dynamics of Aircraft Stalling" Advisory Group for Aerospace Research and Development Report No. CP-102, November 1972.

20. Francis, R. H. and Pringle, G. E.: "Notes on Longitudinal Stability at Low Speed," Aeronautical Research Committee of Great Britain R and M No. 1833, May 1938.

21. Frederiksen, J. T.: "An Evaluation of the Longitudinal Dynamic Stability of an Aircraft at Stall," Master's Thesis from Naval Postgraduate School, June 1972.

22. Fuchs, R. and Schmidt, W.: "The Dangerous Sideslip of a Stalled Airplane and its Prevention," NACA TM No. 638, September 1931.

23. Garner, H. M. and Wright, K. V.: "The Longitudinal Control of an Aeroplane Beyond the Stall," Aeronautical Research Committee of Great Britain R and M No. 1193, May 1928.

24. Gates, S. B.: "Notes on Longitudinal Stability at Stalling in Gliding Flight," Aeronautical Research Committee of Great Britain R and M No. 1189, June 1928.

25. Gault, D. E.: "A Correlation of Low-Speed, Airfoil-Selection Stalling Characteristics with Reynolds Number and Airfoil Geometry," NACA Report No. TN 3963, March 1957.

26. "General Aviation Aircraft Safety," Princeton University Conference, October 24-25, 1973, Federal Aviation Administration Report No. FAA-RD-74-154, October 1974.

27. Gregory, N., Quiney, V. G., O'Reilly, C. L., and Hall, D. J.: "Progress Report on Observations of Three-Dimensional Flow Patterns Obtained During Stall Development on Aerofoils and on the Problem of Measuring Two-Dimensional Characteristics," Aeronautical Research Council of Great Britain C.P. No. 1146, 1971.

28. Hancock, G. J.: "Problems of Aircraft Behaviour at High Angles of Attack," Advisory Group for Aerospace Research and Development AGARDograph No. 136, April 1969.

29. Hoerner, Ing. S. F.: "Maximum Lift and Stalling," Fluid-Dynamic Lift, Chapter 4, Published by Mrs. L. A. Hoerner, 1975.

30. Hurley, F. X.: "Airfoil Pressure Distributions in Low-Speed Stall," Journal of Aircraft, Vol. 6, No. 5, September-October 1969, pp. 474-475.

31. Jones, M. B.: "An Experimental Study of the Stalling of Wings," Aeronautical Research Committee of Great Britain R and M No. 1588, December 1933.

32. Kao, H. C.: "Some Aspects of Airfoil Stall in Low-Speed Flow," Journal of Aircraft, Vol. 11, No. 3, March 1974, pp. 177-180.

33. Kline, S. J.: "On the Nature of Stall," Stanford University Report No. MD-4, June 1958.

34. Langewiesche, W.: "Blind Spots in Flight Instruction. Part I - The Stall," Airfacts, June 1973, pp. 70-79.

35. McCullough, G. B. and Gault, D. W.: "Examples of Three Representative Types of Airfoil-Section Stall at Low Speed," NACA Report No. TN 2502, September 1951.

36. McRae, D. M.: "The Aerodynamics of High Lift Devices on Conventional Aircraft. Part I - General Description and Comments on $C_{L_{max}}$ and Stalling Behaviour," The Aeronautical Journal of the Royal Aeronautical Society, Vol. 73, June 1969, pp. 535-541.

37. Moore, T. W. F.: "A Note on the Causes of Thin Airfoil Stall," Aeronautical Research Council of Great Britain F.M. No. 2785, February 16, 1959.

38. Naito, K.: "Stall Performance," U.S. Army Material Command, Foreign Science and Technology Command Report No. F STC-HT-23-1183-71, April 1971.

39. Reilly, D. N.: "A Useful Method of Airfoil Stall Prediction," Journal of Aircraft, Vol. 4, No. 6, November-December 1967, pp. 567-568.

40. Saul, C. W.: "Evaluation of Minimum Aircraft Flying Speed by Digital Simulation," Master's Thesis from Naval Postgraduate School, June 1972.

41. Soule', H. A. and Gough, M. N.: "Some Aspects of the Stalling of Modern Low-Wing Monoplanes," NACA Report No. TN 645, April 1938.

42. "Stall/Post-Stall/Spin Symposium Proceedings," Aeronautical Systems Division, U.S. Air Force Flight Dynamics Laboratory, December 15-17, 1971.

43. Thain, J. A.: "Reynolds Number Effects at Low Speeds on the Maximum Lift of Two-Dimensional Aerofoil Sections Equipped with Mechanical High Lift Devices," Quarterly Bulletin of the Division of Mechanical Engineering and the National Aeronautical Establishment, Report No. DME/NAE 1973(3), July 1-September 30, 1973.

44. Thomas, H. H. B. M. and Collingbourne, J.: "Longitudinal Motions of Aircraft Involving High Angles of Attack," Aeronautical Research Council of Great Britain R and M No. 3753, January 1973.

45. Thomas, H. H. B. M.: "On Problems of Flight Over an Extended Angle of Attack Range," The Aeronautical Journal of the Royal Aeronautical Society, Vol. 77, August 1973, pp. 412-423.

46. Tobak, M. and Schiff, L.: "Nonlinear Aerodynamics of Aircraft in High Angle-of-Attack Maneuvers," AIAA Paper No. 74-85, 12th Aerospace Sciences Meeting, January 30-February 1, 1974.

47. Van den Berg, B.: "Reynolds Number and Mach Number Effects on Maximum Lift and the Stalling Characteristics of Wings at Low Speeds," National Aerospace Laboratory of the Netherlands, Report No. NLR TR 69025U, March 1969.

48. Winter, W.: "I Learn About Stalls," Air Facts, Vol. 10, No. 12, December 1947, pp. 41-49.

STALL WARNING

49. Anderson, C. A. and Walker, J. E., III: "A Stall Inhibitor for the F-111," Proceedings of the National Aerospace Electronics Conference, May 15-17, 1972, pp. 222-226.

50. Anderson, S. B.: "Correlation of Pilot Opinion of Stall Warning with Flight Measurements of Various Factors which Produce the Warning," NACA Report No. TN 1868, April 1949.

51. Bahns, E. L. and Bock, C. C., Jr.: "Evaluation of the Monitor Angle of Attack/Stall Warning System Installed in a C-130E Aircraft," U.S. Air Force Flight Test Center Report No. FTC-TR-65-23, August 1965.

52. Bennett, G. and Owens, J. K.: "Flight Test of a Stall Sensor and Evaluation of its Application to an Aircraft Stall Deterrent System Using the NASA LRC General Aviation Simulator," Mississippi State University Report, March 1976.

53. Bethwaite, C. F. and Langley, R. A., Lt.: "Note on Research into Some Aspects of Stall Warning Devices," The College of Aeronautics, Cranfield, Great Britain, Report No. 72, April 1953.

54. Bethwaite, C. F.: "Note on the Development of a Trailing-Edge Flap as a Stall Detector," The College of Aeronautics, Cranfield, Great Britain, Report No. 75, September 1953.

55. Bull, G.: "Development of Stall Warning for the T-34B Airplane," Cornell Aeronautical Laboratory Report No. IH-1019-F-1, November 1, 1965.

56. Carlile, H. J., Maj.: "Final Report on Evaluation of Monitor Angle of Attack Indicator System," U.S. Air Force Special Warfare Center Technical Documentary Report No. SAWC-TDR-64-105, June 1966.

57. Collins, L.: "The Safe Flight Indicator," Air Facts, Vol. 10, No. 8, August 1947, pp. 49-55.

58. Donnelly, T. S.: "An Improved Stall Warning System for General Aviation Aircraft," SAE Paper No. 720331, Business Aircraft Meeting, March 15-17, 1972.

59. "Flight Evaluation of an Audio Stall Warning System for the F-4 Airplane," U. S. Naval Air Test Center Report No. ST-45R-69, June 3, 1969.

60. Gilson, R. D. and Fenton, R. W.: "Development of a Stall Deterrent Device for Small Airplanes," Federal Aviation Administration Report No. FAA-RD-75-53, June 1975.

61. Grambart, J. E.: "Reduction of Stall-Spin Accidents Related to Take-off, Departure, and Landing," Federal Aviation Administration Report No. NA-68-4, February 1968.

62. Harding, J. H.: "Evaluation of the Upson Stall Warning Indicator," Civil Aeronautics Administration, Technical Development Report No. 213, September 1953.

63. Heller, H. H., Bliss, D. B., and Widnall, S. E.: "Incipient Stall Detection through Unsteady-Pressure Monitoring on Aircraft Wings," Journal of Aircraft, Vol. 9, No. 2, February 1972, pp. 186-188.

64. "KC-130F Airplane NATOPS Obstacle Approach-Angle of Attack Evaluation, Final Report," U.S. Naval Air Test Center Report No. FT-21R-73, April 16, 1973.

65. Kellum, W. E., Rulon, P. J., Hill, J. J., Vaughn, K. W., and Niven, J. I.: "A Study of the Adequacy of the Stall Warning Characteristics of the SNJ Aircraft," National Research Council Report No. 7, July 1950.

66. Lambdin, R. L.: "Aerodynamic Study for Development of an Optimum Angle of Attack Display System," Aeronautical Systems Division, U.S. Air Force Flight Dynamics Laboratory, Report No. ASD-TR-73-55, July 1973.

67. LaPlant, P., II and Johnson, A. P.: "Evaluation of the Giannini Dual Stall Warning System and Stall Margin Indicators Installed in a C-133D," U. S. Air Force Flight Test Center Report No. FTC-TR-67-5, May 1967.

68. Mellinger, B. L., Kramer, R. M., and Griffiths, D. M.: "Design Definition Study Universal Stall Margin Indicating System," Aeronautical Systems Division, U. S. Air Force Systems Command, Report No. ASD-TR-69-91, December 1969.

69. Mullowney, P. E., Jr.: "The Design, Fabrication, and Evaluation of the Aural Angle of Attack/Stall Warning System," Master's Thesis from Naval Postgraduate School, June 1973.

70. Odle, M. L.: "ATC Angle of Attack Training," U. S. Air Force Instrument Flight Test Center, Randolph AFB, Report No. IFC-TR-72-3, July 1972.

71. O'Leary, C. O.: "A Review of Stall Warning Devices," Royal Aircraft Establishment of Great Britain, Technical Memo No. Aero 882, April 1965.

72. Ontiveros, R. J.: "Experimentation and Evaluation of Improved Stall Warning Equipment," Federal Aviation Administration Report No. NA-69-35, December 1969.

73. Scott, B.: "Experimentation and Evaluation of Improved Stall Warning Equipment Phase II," Federal Aviation Administration Report No. FAA-TD-73-179, May 1974.

74. Taylor, R. K.: "Operational Test and Evaluation, Automated Specialties Normalized Angle of Attack System," U.S. Air Force Instrument Flight Test Center, Randolph AFB, Report No. IFC-TR-72-1, May 1972.

75. Thompson, F. L.: "NACA Stall Warning Indicator," NACA Report No. TN-670, October 1938.

76. Warren, R. W. and Swartz, E. L.: "Fluidic Stall Sensing System," U.S. Army Aviation Laboratory Technical Report No. 1368, February 1968.

77. Zaloucik, J. H.: "Summary of Stall-Warning Devices," NACA Report No. TN 2676, May 1952.

IMPROVING THE CHARACTERISTICS OF THE STALL

78. Anderson, R. F.: "A Comparison of Several Tapered Wings Designed to Avoid Tip Stalling," NACA Report No. TN 713, June 1939.

79. Bull, G.: "Investigation of Lateral Stability at Stall," Cornell Aeronautical Laboratory, WADC Technical Report No. 54-498, February 1954.

80. Burris, W. R. and Hutchins, D. E.: "Effect of Wing Leading-Edge Geometry on Maneuvering Boundaries and Stall Departure," AIAA Paper No. 70-904, 2nd Aircraft Design and Operations Meeting, July 20-22, 1970.

81. Campbell, G. F. and Bull, G.: "Analytical Investigation of Lateral Motions of an Airplane at the Stall with and without Autopilot," Cornell Aeronautical Laboratory Report No. TB-556-F-1, April 7, 1949.

82. Chen, R. T. N., Newell, F. D., and Schelhorn, A. E.: "Development and Evaluation of an Automatic Departure Prevention System and Stall Inhibitor for Fighter Aircraft," Calspan Corporation Technical Report No. AFFDL-TR-73-29, April 1973.

83. Chevalier, H. I.: "Aerodynamic Spoiler for Preventing Airplane Stall/ Spin Type Accidents," Flight Mechanics Laboratory, Texas A and M University, Federal Aviation Administration Report No. FAA-RD-75-21, December 1974.

84. Chevalier, H. and Brusse, J. C.: "A Stall/Spin Prevention Device for General-Aviation Aircraft," SAE Paper No. 730333, Business Aircraft Meeting, April 3-6, 1973.

85. "Easily Piloted Light 'Plane of the Future' Seen in General Aircraft's New Skyfarer," American Aviation, Vol. 5, No. 2, June 15, 1941, pp. 20-21.

86. "Ercoupe," Air Facts, Vol. 3, No. 5, May 1940, pp. 19-33.

87. "Flight Training on the Ercoupe," Air Facts, Vol. 3, No. 9, September 1940, pp. 13-19.

88. Hunter, P. A. and Vensel, J. R.: "A Flight Investigation to Increase the Safety of a Light Airplane," NACA Report No. TN 1203, March 1947.

89. Irving, H. B. and Batson, A. S.: "Some Early Model Experiments on Devices for Improving Lateral Control Near the Stall," Aeronautical Research Committee of Great Britain R and M No. 1251, 1929.

90. Jacobs, E. N.: "Tapered Wings, Tip Stalling, and Preliminary Results from Tests of the Stall-Control Flap," NACA Wartime Report No. L-296, November 1937.

91. Jones, E. T., Eng, M., Maitland, C. E., and Purdin, W. E.: "Stalled Flight Tests of a Moth Fitted with Auto Control Slots and Interceptors," Aeronautical Research Committee of Great Britain R and M No. 1292, November 1929.

92. Kroeger, R. A. and Feistel, T. W.: "Reduction of Stall-Spin Entry Tendencies through Wing Design," SAE Paper No. 760481, Business Aircraft Meeting, April 6-9, 1976.

93. Langewiesche, W.: "The Elevator Doesn't Elevate," Air Facts, Vol. 6, No. 3, March 1943, pp. 49-58.

94. Larson, A. E. and Litz, C. J., Jr.: "Emergency Control of Boundary Layer on Aircraft Wings by Propellant Energy," U. S. Army Frankford Arsenal Report No. R-1675, April 1963.

95. Larson, A. E. and Litz, C. J., Jr.: "A Possible Cure for Stalls," Army Aviation Digest, July 1964, pp. 22-23.

96. Lehnert, R. F.: "Emergency Control of Boundary Layer on Aircraft Wings by Propellant Energy - Propellant Actuated Device (PAD) Antistall," U. S. Army Frankford Arsenal Report No. M66-13-1, Princeton University Report No. 758, October 1965.

97. Moeller, C. A., III: "The Case of the 'Unconventional' Lightplane," Air Facts, Vol. 6, No. 3, March 1943, pp. 60-66.

98. Raspet, A., Cornish, J. J., III, and Bryant, G. D.: "Delay of the Stall by Suction through Distributed Perforations," Paper at Institute of the Aeronautical Sciences' 24th Annual Meeting, JAnuary 23-26, 1956, Preprint No. 587.

99. Rutan, B.: "Aerodynamic Design Approach to the Stall/Spin Problem - The Vari Viggen," SAE Paper No. 740391, Business Aircraft Meeting, April 2-5, 1974.

100. "Safety Plane " Air Facts, Vol. 2, No. 13, December 1939, pp. 5-8.

101. Schuler, J. M.: "Flight Evaluation of an Automatic Control System for Stabilizing the Large Uncontrolled Motions of Airplanes in Stalled Flight," Cornell Aeronautical Laboratory Report No. TB-1132-F-2, October 1959.

102. "Skyfarer," Air Facts, Vol. 4, No. 7, July 1, 1941, pp. 14-23.

103. Smetana, F. O., Summey, D. C., and Johnson, W. D.: "Riding and Handling Qualities of Light Aircraft - A Review and Analysis," NASA Contractor Report No. CR-1975, March 1972.

104. Soule', H. A. and Anderson, R. F.: "Design Charts Relating to the Stalling of Tapered Wings," NACA Report No. 703, 1940.

105. Spahr, J. R. and Christophersen, D. R.: "Measurements in Flight of the Stability, Lateral-Control, and Stalling Characteristics of an Aircraft Equipped with Full-Span Zap Flaps and Spoiler-Type Ailerons," NACA Wartime Report No. A-28, December 1943.

106. Sweberg, H. H. and Dingeldein, R. C.: "Summary of Measurements in Langley Full-Scale Tunnel of Maximum Lift Coefficients and Stalling Characteristics of Airplanes," NACA Wartime Report No. L-145 (ACR No. L5C24), April 1945.

107. Von Rosenberg, C. W., Keen, F.R., and Mohler, S. H.: "The 'Stall Barrier' as a New Preventive in General Aviation Accidents," Federal Aviation Administration Report No. AM66-31, September 1966.

108. Weick, F. E. and Abramson, H. N.: "Investigation of Lateral Control Near the Stall - Analysis for Required Longitudinal Trim Characteristics and Discussion of Design Variables," NACA Report No. TN 3677, June 1956.

109. Weick, F. E. and Abramson, H. N.: "Investigation of Lateral Control Near the Stall - Flight Tests with High-Wing and Low-Wing Monoplanes of Various Configurations," NACA Report No. TN 3676, June 1956.

110. Weick, F. E.: "Preliminary Investigation of Modifications to Conventional Airplanes to Give Nonstalling and Short-Landing Characteristics," NACA Report No. TN 418, January 1972.

111. Weick, F. E., Sevelson, M. S., McClure, J. G., and Flanagan, M. D.: "Investigation of Lateral Control Near the Stall - Flight Investigation with a Light High-Wing Monoplane Tested with Various Amounts of Washout and Various Lengths of Leading-Edge Slot," NACA Report No. TN 2948, May 1953.

112. Weick, F. E.: "Thoughts on Mush/Stall Spin Accidents and How to Avoid Them," Sport Aviation, January 1975, pp. 31-34.

113. Weick, F. E. and Wenzinger, C. J.: "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part I - Ordinary Ailerons on Rectangular Wings," NACA Report No. 419, 1932.

114. Weick, F. E. and Noyes, R. W.: "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part II - Slotted Ailerons and Frise Ailerons," NACA Report No. 422, 1932.

115. Weick, F. E. and Wenzinger, C. J.: "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part III - Ordinary Ailerons Rigged Up 10^{o} when Neutral," NACA Report No. 423, 1932.

116. Weick, F. E. and Harris, T. A.: "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part IV - Floating Tip Ailerons on Rectangular Wings," NACA Report No. 424, 1932.

117. Weick, F. E. and Shortal, J. A.: "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part V - Spoilers and Ailerons on Rectangular Wings," NACA Report No. 439, 1932.

118. Weick, F. E. and Harris, T. A.: "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part VI - Skewed Ailerons on Rectangular Wings," NACA Report No. 444, 1932.

119. Weick, F. E. and Wenzinger, C. J.: "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part VII - Handley Page Tip and Full-Span Slots with Ailerons and Spoilers," NACA Report No. TN 443, January 1933.

120. Weick, F. E. and Shortal, J. A.: "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part VIII - Straight and Skewed Ailerons on Wings with Rounded Tips," NACA Report No. TN 445, February 1933.

121. Weick, F. E. and Wenzinger, C. J.: "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part IX - Tapered Wings with Ordinary Ailerons," NACA Report No. TN 449, February 1933.

122. Weick, F. E. and Noyes, R. W.: "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part X - Various Control Devices on a Wing with a Fixed Auxiliary Airfoil," NACA Report No. TN 451, March 1933.

123. Weick, F. E. and Harris, T. A.: "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part XI - Various Floating Tip Ailerons on Both Rectangular and Tapered Wings," NACA Report No. TN 458, May 1933.

124. Weick, F. E. and Wenzinger, C. J.: "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part XII - Upper-Surface Ailerons on Wings with Split Flaps," NACA Report No. 499, 1934.

125. Weick, F. E. and Noyes, R. W.: "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. Part XIII - Auxiliary Airfoils Used as External Ailerons," NACA Report No. 510, 1935.

126. Wimpenny, J. C.: "Low-Speed Stalling Characteristics," Advisory Group for Aeronautical Research and Development Report No. 356, April 1961.

127. Young, A. D.: "A Review of Some Stalling Research," Royal Aircraft Establishment of Great Britain R and M No. 2609, February 1942.

CHARACTERISTICS OF THE SPIN

128. Blodgett, R.: "Spins," Flying, November 1972, pp. 86-88, 91.

129. Bowman, J. S., Jr. and Burk, S. M., Jr.: "Stall/Spin Research Status Report," SAE Paper No. 740354, Business Aircraft Meeting, April 2-5, 1974.

130. Bowman, J. S.: "Airplane Spinning," Proceedings of Conference on Aircraft Operating Problems, NASA SP-83, May 10-12, 1965, pp. 265-269.

131. Bramson, A.: "More About Spinning," Flight International, December 13, 1973, pp. 981-982.

132. Bramson, A.: "The Spin" The AOPA Pilot, July 1974, pp. 24-27.

133. Bryant, L. W. and Jones, I. M. W.: "Recovery from a Spin," Aeronautical Research Committee of Great Britain R and M No. 1426, March 1932.

134. Buehler, R. R.: "The Derivation, Solution, and Analysis of Airplane Spin Equations Modeled in an Inertial Coordinate System," Master's Thesis from Naval Postgraduate School, March 1972.

135. Flight Instructor Bulletin, Federal Aviation Administration Central Region, No. 18, August 1975.

136. Griscom, R.: "The Ounce of Prevention," Western Aviation, August 1975, p. 17.

137. Johnson, A. E.: "A Literature Survey of the Problem of Aircraft Spins," Master's Thesis from Naval Postgraduate School, September 1971.

138. Langewiesche, W.: "The Spin Over the Top and the Overbanking Tendency," Air Facts, Vol. 7, No. 4, April 1944, pp. 64-82.

139. Lekowski, M. and Petulski, J.: "Investigation of Aircraft Spins," U. S. Air Force Systems Command, Foreign Technology Division Report No. FTD-HC-23-0555-72, June 1972.

140. Neihouse, A. I., Klinar, W. J., and Scher, S. H.: "Status of Spin Research for Recent Airplane Designs," NASA Report No. TR R-57, 1960.

141. Scher, S. H.: "Pilot's Loss of Orientation in Inverted Spins," NACA Report No. TN 3531, October 1955.

142. Scher, S. H.: "Post-Stall Gyrations and their Study on a Digital Computer," Advisory Group for Aerospace Research and Development Report No. 359, April 1961.

143. Sewell, C. A. and Whipple, R. D.: "Initial Spin Tests," Pilot's Handbook for Critical and Exploratory Flight Testing, Society of Experimental Test Pilots, 1972, pp. 36-56.

144. Stone, R. W., Garner, W. G., and Gale, L. J.: "Study of Motion of Model of Personal-Owner or Liaison Airplane through the Stall and into the Incipient Spin by Means of a Free-Flight Testing Technique," NACA Report No. TN-2923, April 1953.

145. Weissman, R.: "Status of Design Criteria for Predicting Departure Characteristics and Spin Susceptibility," Journal of Aircraft, Vol. 12, No. 12, December 1975, pp. 989-993.

146. Wykes, J. H., Casteel, G. R., and Collins, R. A.: "An Analytical Study of the Dynamics of Spinning Aircraft. Part I - Flight Test Data and Spin Calculations," U.S. Air Force, Wright Air Development Center Technical Report No. 58-381, December 1958.

147. Wykes, J. H., Casteel, G. R., and Collins, R. A.: "An Analytical Study of the Dynamics of Spinning Aircraft. Part II - Wind Tunnel Tests," U. S. Air Force, Wright Air Development Center Technical Report No. 58-381, December 1958.

IMPROVING THE CHARACTERISTICS AND THE RECOVERY OF THE SPIN

148. Bowman, J. S., Jr. and Burk, S. M., Jr.: "Stall/Spin Studies Relating to Light General-Aviation Aircraft," SAE Paper No. 730320, Business Aircraft Meeting, April 3-6, 1973.

149. Bowman, J. S., Jr.: "Summary of Spin Technology as Related to Light General Aviation Airplanes," NASA Report No. TN D-6575, December 1971.

150. Gale, L. J. and Jones, I. P., Jr.: "Effects of Antispin Fillets and Dorsal Fins on the Spin and Recovery Characteristics of Airplanes as Determined from Free-Spinning-Tunnel Tests," NACA Report No. TN 1779, December 1948.

151. Klinar, W. J. and Snyder, T. L.: "Influence of Tail Length Upon the Spin-Recovery Characteristics of a Trainer-Type-Airplane Model," NACA Report No. TN 1764, December 1948.

152. Klinar, W. J. and Wilson, J. H.: "Spin Tunnel Investigation of the Effects of Mass and Dimensional Variations on the Spinning Characteristics of a Low-Wing Single-Vertical-Tail Model Typical of Personal-Owner Airplanes," NACA Report No. TN 2352, May 1951.

153. Neihouse, A. I.: "The Effect of Variations in Moments of Inertia on Spin and Recovery Characteristics of a Single-Engine Low-Wing Monoplane with Various Tail Arrangements, Including a Twin Tail," NACA Report No. TN 1575, May 1948.

154. Neihouse, A. I.: "A Mass-Distribution Criterion for Predicting the Effect of Control Manipulation on the Recovery from a Spin," NACA Wartime Report No. L-168, August 1942.

155. Neihouse, A. I. and Pitkin, M.: "Effect of Wing Leading-Edge Slots on the Spin and Recovery Characteristics of Airplanes," NACA Wartime Report No. L-504, April 1943.

156. Seidman, O. and Neihouse, A. I.: "Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails, Part I - Basic Loading Condition," NACA Report No. TN 608, August 1937.

157. Seidman, O. and Neihouse, A. I.: "Free-Spinning Wind-Tunnels Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails. Part IV - Effect of Center-of-Gravity Location," NACA Report No. 672, 1939.

158. Seidman, O. and Neihouse, A. I.: "Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails. Part V - Effect of Airplane Relative Density," NACA Report No. 691, 1940.

159. Stone, R. W., Jr. and Klinar, W. J.: "The Influence of Very Heavy Fuselage Mass Loadings and Long Nose Lengths Upon Oscillations in the Spin," NACA Report No. TN 1510, January 1948.

160. Young, J. W.: "Optimal and Suboptimal Control Technique for Aircraft Spin Recovery," NASA Report No. TN D-7714, October 1974.

161. Zimmerman, C. H.: "Effect of Changes in Tail Arrangement Upon the Spinning of a Low-Wing Monoplane Model," NACA Report No. TN 570, June 1936.

WIND-TUNNEL TESTS OF TYPICAL GENERAL AVIATION AIRCRAFT

162. Fink, M. P. and Freeman, D. C., Jr.: "Full-Scale Wind-Tunnel Investigation of Static Longitudinal and Lateral Characteristics of a Light Twin-Engine Airplane," NASA Report No. TN D-4983, January 1969.

163. Fink, M. P., Freeman, D. C., Jr., and Greer, H. D.: "Full-Scale Wind-Tunnel Investigation of the Static Longitudinal and Lateral Characteristics of a Light Single-Engine Airplane," NASA Report No. TN D-5700, March 1970.

164. Fink, M. P., Shivers, J. P., Greer, H. D., and Megrail, J. L.: "The Effects of Configuration Changes on the Aerodynamic Characteristics of a Full-Scale Mockup of a Light Twin-Engine Airplane," NASA Report No. TN D-6896, September 1972.

165. Fink, M. P., Shivers, J. P., and Smith, C. C., Jr.: "A Wind-Tunnel Investigation of Static Longitudinal and Lateral Characteristics of a Full-Scale Mockup of a Light Twin-Engine Airplane," NASA Report No. TN D-6238, 1971.

166. Greer, H. D., Shivers, J. P., Fink, M. P., and Carter, C. R.: "Wind-Tunnel Investigation of Static Longitudinal and Lateral Characteristics of a Full-Scale Mockup of a Light Single-Engine High-Wing Airplane," NASA Report No. TN D-7149, May 1973.

167. Shivers, J. P., Fink, M. P., and Ware, G. M.: "Full-Scale Wind-Tunnel Investigation of the Static Longitudinal and Lateral Characteristics of a Light Single-Engine Low-Wing Airplane," NASA Report No. TN D-5857, June 1970.